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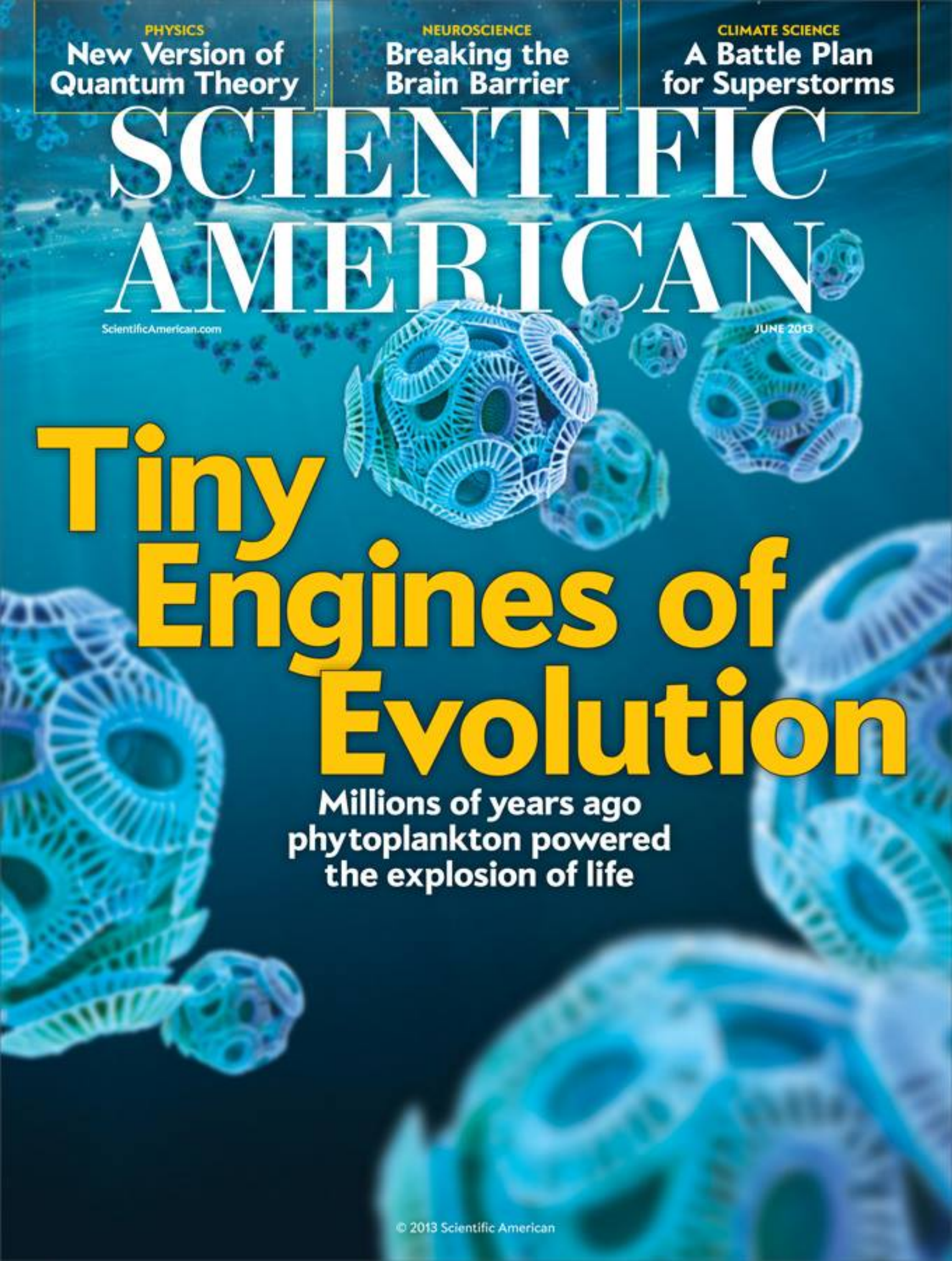
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JUNE 2013



Tiny Engines of Evolution

Millions of years ago phytoplankton powered the explosion of life

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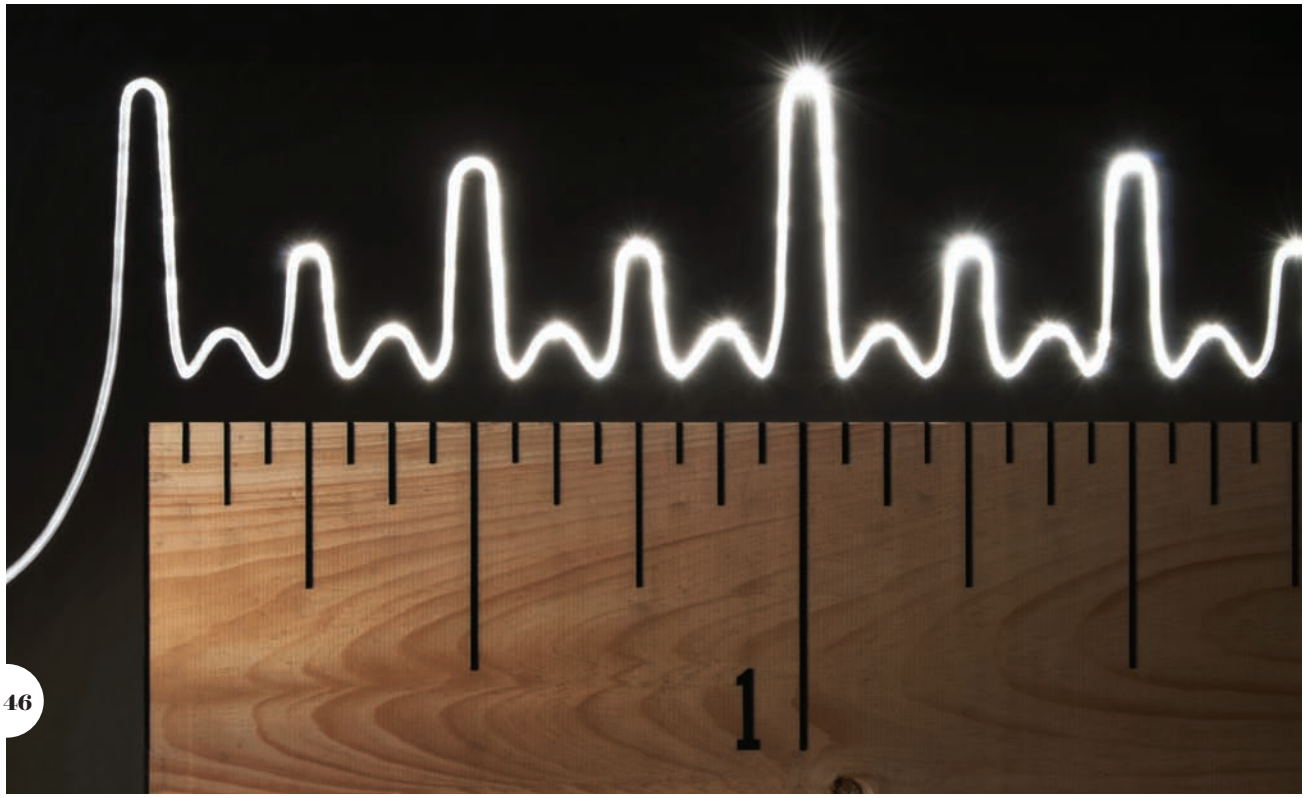
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June 2013 Volume 308, Number 6

ON THE COVER



Increases in the abundance and nutrient content of minuscule aquatic plants known as phytoplankton probably helped to power a dramatic diversification of marine animals that started a quarter of a billion years ago. Photography by Chris Ross, Getty Images (*background*); Steve Gschmeissner, Science Source (*phytoplankton*).



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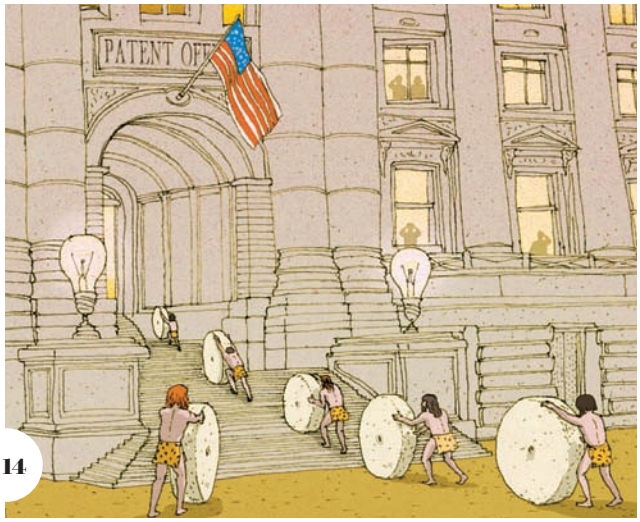
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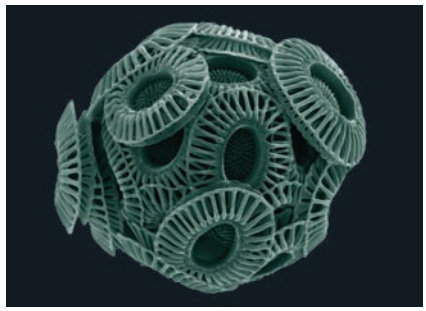
Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina



A Science Journey

ONE OF THE PLEASURES OF *Scientific American* is the way it invites us to journey to the frontiers of knowledge, accompanied by the scientists who are working on the boundaries. In this issue's cover story, "Tiny Plants That Once Ruled the Seas," researchers Ronald Martin and Antonietta Quigg conjure the idea of stepping into an imaginary time machine, with the dial turned back to 500 million years ago. There we witness the watery ways of early life on the earth, when clamlike creatures and trilobites dominated the seas. We watch as the millennia then unfold before us in subsequent eras, with marine life diversifying with remarkable speed. What was the root cause that enabled the early blooming of species?

In their feature, starting on page 40, Martin and Quigg point to a tiny font for such richness: microscopic phytoplankton. These "modest plants" increased the nutrient content available, which "fueled the rise of the modern marine fauna."



FUEL: Microscopic plants fed evolution.

The quantum realm, where particles can be in two places at once and information seems to travel faster than light speed, also beckons armchair travelers in Hans Christian von Baeyer's article, "Quantum Weirdness? It's All in Your Mind," beginning on page 46. Von Baeyer takes us on a tour through a new version of quantum theory, which suggests that quantum information may exist only in the mind. At times, it seems that the strangest and most wondrous travels both start from and end in our own internal worlds. SA

ONLINE

Editors on Video

For the past year *Scientific American* has offered shows on Space Lab, a channel originated by our partners at YouTube. Now we will supply all of Space Lab's programming on YouTube. Here's what you will find each month. First, the Countdown, a biweekly show hosted by science journalist Sophie Bushwick, brings you the top space news. You can watch It Happened in Space for Amy Shira Teitel's fact-filled historical videos. And in our Ask the Experts, you can have your burning questions answered by the pros.

Want more? Check out our Instant Egghead short videos, which explain everyday science phenomena such as why we get "brain freeze" from cold drinks, the life cycle of a bruise and why chimps are stronger than humans.

Find them all on YouTube and at www.ScientificAmerican.com. —*M.D.*

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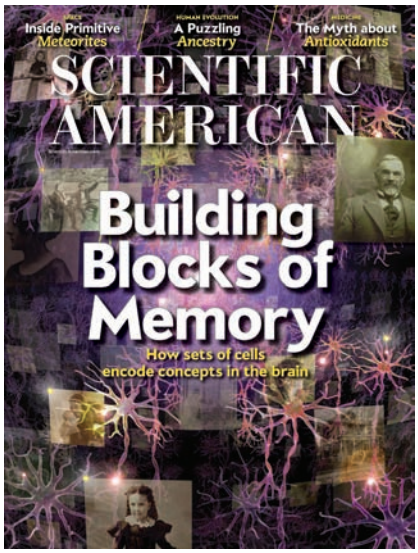
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STEVE GSCHMEISSNER *Science Source (phytoplankton)*

Illustration by Nick Higgins

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February 2013

ANTIOXIDANTS AND HEALTH

Although I would not go so far as to say Melinda Wenner Moyer's "The Myth of Antioxidants" established "myth" status for antioxidants, it was an eye-opening account of recent experimental evidence demonstrating that an increase in free radical levels in living systems does not consistently correlate with shorter life spans and that the aging process contains more uncharted territory than initially believed. More important, however, no reader should come away feeling that vitamins from food products are in any way overrated or are "killers."

The studies that are mentioned in the article repeatedly made use of unnatural (and often unmeasured) vitamin sources, which of course will have the potential to do more harm than good to an organism. As a chemist in the pharmaceutical industry, I can state with considerable certainty that a drug product's formulation, inert substances and potency are equally as critical to its overall safety and efficacy as the active pharmaceutical ingredient, per se.

Case in point, a broccoli floret is a presentation of vitamin C and beta-carotene that the body digests and systemically disperses in a manner more natural and evolved than that of the exact same vitamins presented in tablets and capsules. Ingestion of supplements charges the body with concentrated vitamin doses lacking the beneficial delivery components that broccoli and other vegetables provide in well-received quantities. The generation and buildup of harmful oxidants is thus more likely to occur.

"Foods rich in vitamins and other antioxidants are more beneficial than vitamin supplements."

JOHN J. WALSH *CLEVELAND*

This may seem like a roundabout way of stating the obvious: a diet including foods rich in vitamins and other antioxidants is more beneficial than the routine consumption of vitamin supplements.

John J. Walsh
Cleveland

The article states that roundworms genetically engineered to not produce naturally occurring antioxidants lived as long as worms that produced them, implying that antioxidants are worthless at best. Yet length of life is not the only criterion we should go by. If it were, then you could say that my father-in-law, who never took antioxidants and subsisted almost entirely on candy bars, lived a good life. In fact, he lived to the same age as Jack LaLanne (97). But LaLanne was fit, active and in command of his faculties at the end of his life, whereas my father-in-law spent his declining years in a long, slow descent into the abyss of dementia.

David Blair
via e-mail

Wenner Moyer correctly points out that some studies of the effects of high doses of antioxidant supplements such as beta-carotene or vitamin E have found that they are associated with increased mortality. She fails to mention, however, that those studies were inspired by many others showing that higher levels of such dietary antioxidants in the blood are strongly linked with lower overall mortality and lower death rates from cancer and cardiovascular disease. This is particularly true of the carotenoids, the family of antioxidants related to vitamin A.

Because humans lack the ability to synthesize carotenoids, those measured in the blood must come from diet—especially from fruits and vegetables. Thus, it appears that antioxidant carotenoids derived from natural sources in diet do increase life span, whereas individual carotenoids given in high doses do not.

Will Lassek
University of Pittsburgh

"THE LEFT" AND SCIENCE

Michael Shermer appears to be reaching in his Skeptic column this month ["The Left's War on Science"]. He says that "there is more, and recent, antiscience fare from far-left progressives," yet his examples aren't antiscience at all. "Liberals tend to be antinuclear because of the waste-disposal problem," he says. So are most people—that's why Yucca Mountain hasn't been approved as a repository. "Anti–fossil fuels because of global warming." Global warming is occurring, in large part, because of fossil fuels. "Anti-hydroelectric because dams disrupt river ecosystems." Well, yes, they do (ask any ichthyologist how North American native fishes are doing; ask coastal cities why they are running out of beach sand). "Anti–wind power because of avian fatalities." Again, is this antiscience? No, birds do die in wind turbines (and because of other unnatural structures like mirrored skyscrapers).

Dan Swenson
Chino Hills, Calif.

SHERMER REPLIES: Each of these topics (nuclear energy, fossil fuels, and hydroelectric and wind power) involves complex webs of science, technology, economics and politics. The last two are where an "anti" bias can creep in from the far left. People in that camp tend to oppose anything "unnatural" and favor nature over humans if given the choice. Perhaps instead of "antiscience," it is "antiprogress." Whatever you call it, both the left and the right have their biases that go into influencing public policy relating to these energy technologies.

MELTING SPACE DUST

In "Secrets of Primitive Meteorites," Alan E. Rubin mentions the search for a heating process in the early solar system that

would partly melt dust to form the layered chondrules found in meteorites. He laments the problems with competing ideas for the cause, such as supernova shock waves. I am curious about the viability of the idea that nonaccreted grains were accelerated and heated by close encounters with protoplanetesimals, thereby generating the variable heating required.

JIM BONNE
Cumming, Ga.

RUBIN REPLIES: Protoplanetesimals may be only a few kilometers in size; dust grains flying by such bodies would not be noticeably heated. There was a suggestion in the 1970s that chondrules may have formed by frictional melting of dust grains in the nascent atmospheres of protoplanets. The problem with this scenario is that many chondrules contain silicate grains that are unrelated to their hosts (that is, they may differ in mineral chemistry and have a different oxygen-isotopic composition). These "relict" grains are not simply unmelted host chondrule material; they were derived from a preexisting earlier generation of chondrules.

It is more straightforward to assume that some early chondrules were broken by collisions with other chondrules in the solar nebula and that their fragments were incorporated into dust balls that were later partly remelted. An energy source capable of melting just the outer part of a chondrule and not an interior relict grain is required. That is why many researchers prefer flash-heating mechanisms such as lightning bolts.

GRANDMOTHER CELLS

"Brain Cells for Grandmother," by Rodrigo Quian Quiroga, Itzhak Fried and Christof Koch, describes splendid research suggesting that small sets of neurons code for single concepts in humans. But an important caveat was not mentioned: much of the evidence comes from studies of brains of patients with epilepsy, and it is a leap to assume that epilepsy does not alter neuronal function of these neurons or of other cells and networks in the brain.

MARTIN J. STEINBACH
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Do Not Reanimate

A project to revive long-gone species is a sideshow to the real extinction crisis



"We will get woolly mammoths back." So vowed environmentalist Stewart Brand at the TED conference in Long Beach, Calif., in February in laying out his vision for reviving extinct species. The mammoth isn't the only vanished creature Brand and other proponents of "de-extinction" want to resurrect. The passenger pigeon, Caribbean monk seal and great auk are among the other candidates—all species that blinked out at least in part because of *Homo sapiens*. "Humans have made a huge hole in nature in the last 10,000 years," Brand asserted. "We have the ability now—and maybe the moral obligation—to repair some of the damage."

Just a few years ago such de-extinction was the purview of science fiction. Now it is so near at hand that in March, Brand's Long Now Foundation, along with TED and the National Geographic Society, convened an entire conference on the topic. Indeed, thanks to recent advances in cloning and the sequencing of ancient DNA, among other feats of biotechnology, researchers may soon be able to re-create any number of species once thought to be gone for good.

That does not mean that they should, however. The idea of bringing back extinct species holds obvious gee-whiz appeal and a respite from a steady stream of grim news. Yet with limited intellectual bandwidth and financial resources to go around, de-extinction threatens to divert attention from the modern biodiversity crisis. According to a 2012 report from the International Union for Conservation of Nature, some 20,000 species are currently in grave danger of going extinct. Species today are vanishing in such great numbers—many from hunting and habitat destruction—that the trend has been called a sixth mass extinction, an event on par with such die-offs as the one that befell the dinosaurs (and much else) 65 million years ago. A program to restore extinct species poses a risk of selling the public on a false promise that technology alone can solve our ongoing environmental woes—an implicit assurance that if a species goes away, we can snap our fingers and bring it back.

Ironically, the de-extinction conference immediately followed the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) meeting in Bangkok, which underscored just how devastating the trade has been. Reports released to coincide with the meeting revealed that between 2002 and 2011, the African forest elephant population declined by 62 percent from poaching; that fishing kills at least 100 million sharks a year—many of them members of imperiled species; and that between 2000 and 2012, an average of 110 tigers a year were killed (as few as 3,200 of the cats remain in the wild). Poachers slaughter 30,000 African elephants every year for their ivory—the highest kill rate since the 1980s. At this rate, the species could disappear in two decades. So could Africa's rhinos, prized for their horns.

Already conservationists face difficult choices about which species and ecosystems to try to save, since they cannot hope to rescue them all. Many countries where poaching and trade in threatened species are rampant either do not want to give up the revenue or lack the wherewithal to enforce their own regulations. Against that backdrop, a costly and flamboyant project to resuscitate extinct flora and fauna in the name of conservation looks irresponsible: Should we resurrect the mammoth only to let elephants go under? Of course not.

That is not to say that the de-extinction enterprise lacks merit altogether. Aspects of it could conceivably help save endangered species. For example, extinct versions of genes could be reintroduced into species and subspecies that have lost a dangerous amount of genetic diversity, such as the black-footed ferret and the northern white rhino. Such investigations, however, should be conducted under the mantle of preserving modern biodiversity rather than conjuring extinct species from the grave.

The suggestion that we humans have a moral obligation to resurrect the species that died out by our hand resonates with our sense of justice. Yet the revival of a single extinct beast in a lab does not mark the return of a species, and creating viable populations of extinct animals that could flourish in modern ecosystems is a far more difficult challenge. Surely we have a greater duty to species currently on the brink than to the ones that our ancestors wiped out centuries or millennia ago. SA

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Illustration by Yvetta Fedorova

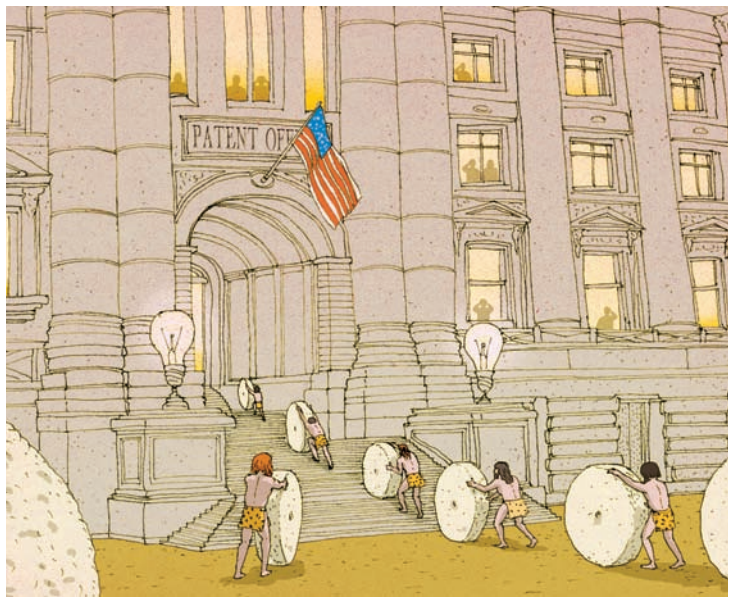
Commentary on science in the news from the experts



David J. Kappos was under secretary of Commerce and director of the U.S. Patent and Trademark Office until January. He is now a partner at the law firm Cravath, Swaine & Moore LLP.

Tweaks to the Idea Factory

How do we recognize an invention when we see one?



The U.S. patent system is a popular target. Recently we have heard that big portfolios of large companies pose a threat to small inventors, "patent trolls" who exist solely to sue real companies have hijacked the marketplace for new ideas and colossal lawsuits prove that America's patent system is broken.

The patent system is indeed in the midst of a challenge. Software technology gives us the GPS in our mobile devices, CT scans that provide early health diagnostics, and other wonders, but circumscribing such technologies in a patent is difficult. Advances in genetics and biotech are critically important to treating many diseases and require huge investments that rely on patent protection, but it is often hard to know where the rights of the inventors end and the public's begin. Should 3-D print files be eligible for patent prosecution? What breadth of protection should be available for the algorithms that extract knowledge from enormous aggregations of data? Each fundamental advance calls for reexamination and adaptation, which is why the patent system is, and must be, the subject of continuous improvement.

Claims that the patent system is broken go back to the proliferation of sewing machines in the mid-1800s. They came up during litigation over automobile patents and again with the advent of the telegraph, electric lighting, aircraft, lasers and microprocessors. Names and technologies change, but the story is the same: halfway to fully deploying the technology du jour, a patent litigation deadlock is declared, calling into question the entire system. In each prior deadlock, litigants settled, courts handed down decisions and things reached a satisfactory end point. This is how the system was designed to work and is working now.

In software, the parties to the various smartphone conflicts, such as in the one between Apple and Samsung, are narrowing their claims to the few patents that truly matter. At the same time, the courts are properly construing many of the patents narrowly (meaning they are not infringed) and providing rulings to allow the parties to work out their remaining differences. In biotech, the Supreme Court has issued guidance narrowing the eligibility of patents on diagnostics, causing innovators to better tailor their patent filings; the court took up patenting of isolated, purified genetic sequences in April, with further guidance to follow.

Given the historical success of American innovation, pragmatism must be the watchword. That is the spirit of the America Invents Act (AIA), the most comprehensive revision to the patent system in generations, signed by President Barack Obama in September 2011 and fully in effect just this spring. The most noticeable change is the transition from a first-to-invent to a first-to-file methodology for awarding patents between competing inventors. This practice will eliminate protracted disputes over who invented what and when that previously were resolved by digging through dusty lab notebooks to prove invention dates. First-to-file replaces this bickering with a simple, objective, fair rule: the first person to come forward with an application for a patent gets the patent. Moving to first-to-file is also a step toward harmonizing our patent system with other countries' systems, an important goal in a global economy.

Beyond first-to-file, the AIA also responds to concerns about the quality of issued patents by providing cost-effective, fast ways to comment on pending patents and to challenge issued ones. These new opportunities apply to all patent applications and patents but are especially helpful in software, where historical references are difficult to find, and in biotech, where fine lines must be drawn between discoveries eligible for protection and ones free for all to use. Still, the AIA has only recently gone into effect, and the ramifications of its new processes and procedures are just beginning to be felt. As *Scientific American*'s March 9, 1878, issue stated, "our Patent Office [is] a great National University, whose diplomas of merit for successful endeavor [are] infinitely more valuable than those of any college." This statement is still true. SA

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Illustration by Izhar Cohen



ASTRONOMY

Cloud to Black Hole: Eat My Dust

This summer's best fireworks may take place at the center of our galaxy

Astronomers have seen it coming. Starting this summer—possibly this month—a large cloud of gas and dust and perhaps a star will begin to ricochet through the dead center of the Milky Way galaxy, the home of a supermassive black hole. The ensuing celestial fireworks should reveal much about the mysterious central core of the galaxy, a region kept shrouded in darkness by dust and distance.

Scientists have long wondered why the black hole at the center of the Milky Way, unlike the black holes at the center of other large galaxies, is perplexingly quiet. It doesn't seem to be gobbling up matter at nearly the rate we would expect.

Unfortunately, the interesting region around the black hole is just too small for our telescopes to resolve from so far away. (Think of painting the *Mona Lisa* on a thumbtack, launching it to the moon, then trying to make out her smile.) Our blurry view makes it hard to understand why it is not flaring with energy as it sucks in gas with the gravitational force of four million suns. This observational frustration is why the incoming cloud is so exciting. "If you watch a meteor go through the atmosphere of Earth, it burns up by friction," says Eliot Quataert, an astrophysicist at the University of California, Berkeley. "We're hoping to see something similar—how the cloud interacts with all the other gas spiraling into the black hole." The cloud will act like a probe, and astronomers will spend years interpreting its readout: a giant cosmic flare.

Researchers are also hoping to sort out exactly where the cloud came from. Some have suggested that two clumps of gas may have collided near the galaxy's center, draining away the momentum that kept them in orbit. Others think the cloud might be a dim, young solar system, the dust not yet petrified into planetary form, the star obscured by gas.

No matter where the unlucky cloud originated from, its fate is sealed: within a few years it will be sucked past the event horizon of the black hole, its existence obliterated. But astronomers will be studying its long farewell, using every kind of telescope available to them. Perhaps the cloud isn't so unlucky after all, suggests Stefan Gillessen, a member of the team that first discovered the cloud in 2011. "It's unlucky in the sense that it will be destroyed," he quips, "but lucky in the sense that it becomes famous." *—Michael Moyer*

Illustration by Don Dixon

ENTOMOLOGY

What's the Buzz?

Sensors in beehives may capture early signs of disease



To the human ear, the buzz of the honeybee can sound like one unchanging hum. Yet a group of researchers hopes that decoding tiny variations in the noise could help halt the catastrophic decline in the world's honeybee population.

The researchers, led by a team at Nottingham Trent University in England, believe the changing sounds from a hive indicate swings in the bees' state of health and that high-tech eavesdropping could provide beekeepers with early-warning signals. Supported by a $1.8-million grant from the European Union, the scientists aim to analyze the buzz from 20 hives kept at a village in rural southeastern France in a five-year experiment that started earlier this spring.

Team leader Martin Bencsik has previously used sensors known as accelerometers to capture a distinct change in bee sounds before the phenomenon known as swarming, which is when the queen quits the hive, taking many of the worker bees with her. The challenge this time is to identify variations in the buzz that can be linked to disease, including colony collapse disorder—a mysterious ailment that has weakened colonies around the world. The researchers' key tool: industrial sensors designed to pick up subtle changes in vibration patterns. Embedded in the wall of the hive, miniature accelerometers will measure the vibrations in the honeycomb caused by the bees' activity and the sounds they create. With no ears, bees are generally thought to rely on vibrations—received through their legs—to communicate with one another.

Researchers in Nottingham will then analyze the data from the hives, using computer software to find telltale correlations between the buzz—its pitch, for example, or the interval between pulses—and the bees' health. Bencsik foresees a time when any worrying changes logged by the accelerometers will trigger an automatic wireless alert to the beekeeper, who can then take swift action.

The trouble is, scientists are still struggling to identify—let alone treat—the main causes of the bees' decline, which some studies have linked to pesticides. "There are lots of suggested treatments, but there is no evidence that any of them work," says Simon Potts, a professor of biodiversity and ecosystem services at the University of Reading in England. Beekeepers must hope that Bencsik's diagnostic tools will come of age at a time when more effective treatments are available. *—William Underhill*

HEALTH

The Doctor Will See You in Aisle 3

Hospitals hope retail clinics will help reduce readmissions

The U.S. has one of the highest hospital readmission rates in the world. About 20 percent of Medicare patients wind up being readmitted within 30 days after discharge. Hospitals have tried a variety of strategies, including patient counseling and home visits to lower readmissions, with mixed results. The office that administers Medicare is hoping that new financial penalties, part of the Affordable Care Act, will push hospitals to tackle the problem more aggressively.

The reasons behind hospital readmissions are complicated and varied. But experts have argued that hospitals could go a long way toward reducing readmissions by ensuring that patients receive proper follow-up care after discharge. To this end, some hospitals are partnering with retail clinics, such as Walgreens's Take Care Clinic and CVS's MinuteClinic. These clinics have medical staff and pharmacies on site, along with flexible hours, and typically do not require appointments. "This brings us out into the community in a way I think could be really beneficial," says David Feinberg, president of the University of California, Los Angeles, Health System, which last summer began a partnership with 11 CVS clinics. So far data on the success of the partnership are only anecdotal, but he and his colleagues are so satisfied with the results they are expanding the program.

Some clinicians have expressed concerns that the standard of care might be lower at retail clinics, which tend to be staffed by nurse practitioners instead of doctors. The current data, however, suggest that the clinic patients are receiving quality care, says Ateev Mehrotra, a policy analyst at Rand Corporation and the University of Pittsburgh. *—Erica Westly*

HEIDI AND HANS-JUERGEN KOCH *Minden Pictures*

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ENGINEERING

Soft Circuits

New netlike circuits could create "cyborg tissues"

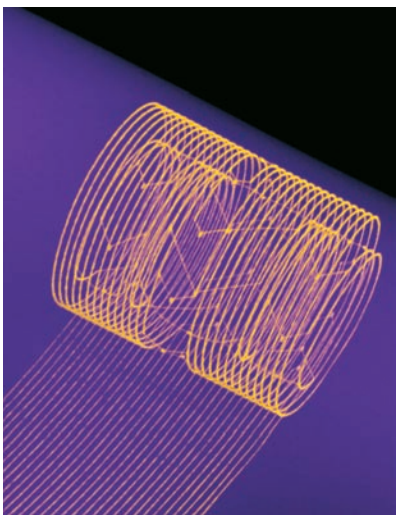
Seamlessly integrating powerful, 3-D computer circuits into soft materials such as rubber has been an elusive goal in engineering. Now researchers say they have developed a type of circuit that is soft and porous—more like a net than a chip. Manufacturers could weave these circuits into an extraordinary range of materials to create "smart matter" that scans and reacts to its surroundings or even "cyborg tissues"—human skin and organs that could report on their own health.

Nanoscientists Jia Liu and Charles Lieber of Harvard University and their colleagues began with silicon wires, each roughly 30 nanometers (billionths of a meter) wide, arranged in two-dimensional circuits. Although some hardened epoxy surrounded the nanowires, these flat circuits were more than 99 percent empty space, resembling nets with large holes. These flexible circuits could then be rolled up like scrolls, creating three-dimensional stacks that could lead to dramatically more powerful computers. The researchers could readily fill the voids in these novel electronics with a wide variety of materials by pouring liquids into the 3-D devices and letting them solidify. The resulting hybrid materials can be "very smart systems," says Liu, whose team detailed its findings online in April in *Proceedings of the National Academy of Sciences USA*.

For instance, electronic networks in silicone rubber can signal when and how the material is deformed—a system that can, for example, warn drivers of damage to a tire before it blows out. Future versions of smart matter could include furniture that tracks vital signs and contact lenses that record and display data, Liu suggests. "We believe our method opens up lots of opportunities to merge electronic systems into every aspect of our life," he says.

"This is groundbreaking research that pushes the electrical sensing device to a new level of complexity and functionality," says materials chemist Yat Li of the University of California, Santa Cruz, who did not take part in this work.

The lattices could also be combined with gels containing living cells. The resulting cyborg tissues could serve as replacements for damaged organs that can give feedback on how they are doing or even enhance human capabilities—cyborg skin, for example, could have extra senses to make it smarter, and cyborg bones and muscles could make people stronger. "Cyborg tissue," Liu says, "will be the most important application from this research." —*Charles Q. Choi*



3-D circuits could enable "smart matter" that reacts to surroundings.

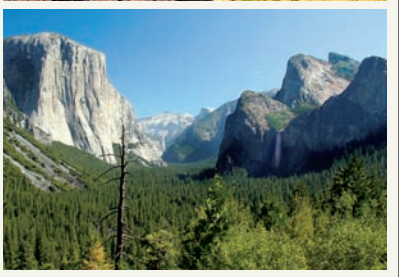
COURTESY OF JIA LIU AND CHARLES LIEBER *Harvard University*

BY THE NUMBERS

69

Percentage of U.S. adults who report having talked on a cell phone while driving in the past 30 days. The rate was higher than in seven European countries also surveyed, where the numbers ranged from 59 percent in Portugal to 21 percent in the U.K., according to a report released in March by the U.S. Centers for Disease Control and Prevention.





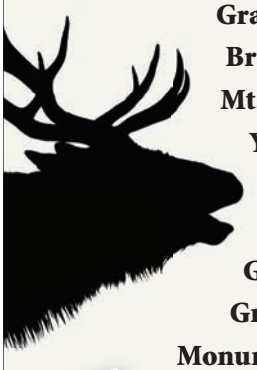


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HEALTH

Mediterranean Mystery

An olive oil compound that makes your throat itch may also help prevent Alzheimer's

Doctors and nutritionists have long associated the Mediterranean diet with human health benefits, including a lower risk of Alzheimer's disease. A recent study of 1,880 elderly people living in New York City, for example, showed that those who strongly adhered to a Mediterranean diet over the study's 14-year span had a 32 to 40 percent lower incidence of Alzheimer's compared with those who did not.

Extra virgin olive oil seems to be one of the main factors behind this risk reduction. People adhering to a Mediterranean diet consume up to 50 milliliters (around one fifth of a cup) of the fragrant green liquid a day. Previously, researchers assumed this benefit came from extra virgin olive oil's high concentration of monounsaturated fatty acids. But in 2005 scientists discovered that oleocanthal—the naturally occurring compound that elicits a peppery, burning sensation in the back of the throat—seemed to produce effects strikingly similar to those of ibuprofen, which tamps down inflammation. Since then, investigators have turned their attention to the potential benefits of this particular compound.

Some studies have shown that oleocanthal interferes with the formation of characteristic neurofibrillary tangles and beta-amyloid plaques, both of which play principal roles in Alzheimer's neurological devastation. Research published online in *ACS Chemical Neuroscience* in February offers new details on how the compound works. The study authors applied different concentrations of oleocanthal over three days to mouse brain cell cultures. They also administered oleocanthal to live mice—the first time such an experiment has been done—every day for two weeks. In both trials, levels of two proteins that play major roles in transporting beta-amyloid out of the brain as well as enzymes that degrade beta-amyloid increased significantly after administering oleocanthal.

The researchers also introduced beta-amyloid to the live mice brains. Compared with control groups, the mice that were given oleocanthal showed significantly enhanced clearance and degradation of the beta-amyloid peptides. "We're trying to further understand oleocanthal's mechanism and maybe eventually try to find compounds that can work in the same way for drug development," says Amal K. Kaddoumi, an assistant professor of pharmaceutics at the University of Louisiana at Monroe and one of the paper's authors. The findings, she notes, most likely have more application for Alzheimer's prevention than treatment. She also thinks that other factors, besides high olive oil consumption, account for the so-called Mediterranean miracle, such as exercise and the large helpings of fresh vegetables that people in that region regularly consume.

Oleocanthal is one of several compounds that scientists have been working with to clear beta-amyloid from the brain. Others include an older skin cancer drug that last year helped alleviate Alzheimer's symptoms in mice and antibodies that bind directly to beta-amyloid and remove it. "This paper is beginning to close in on what the specific components are in these more nutraceutical remedies that are actually helping us," says Kenneth S. Kosik of the University of California, Santa Barbara.

Kosik points out, however, that until clinical trials in humans take place, people must be cautious in interpreting the results. Kaddoumi's group is working to secure funding for just such clinical trials.

—Rachel Nuwer

Illustrations by Thomas Fuchs

PATENT WATCH

Spider silk proteins and methods for producing spider silk proteins: Dragline silk is the toughest kind of spider silk. By weight, it is tougher than Kevlar, which is used in bulletproof vests. But researchers have trouble spinning silk proteins into usable material. Patent no. 8,278,416 details two modified spider silk proteins and describes how they can be coaxed to self-assemble. The resulting material is nontoxic, biodegradable, as well as "strong and elastic like natural silk," says My Hedhammar of the Swedish University of Agricultural Sciences and director of R&D at Spiber Technologies in Uppsala. Hedhammar and her colleagues synthesized the proteins by shortening the sequence of genes found in the spiders and inserting it into the bacterium *Escherichia coli*, which then produced large quantities of the proteins.

The finished fibers are strong and can be woven, spun, twisted or even crocheted into a silk-like material. Future applications could include wound dressing and tissue scaffolds for regenerative medicine. —*Marissa Fessenden*



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MEDICINE

"Nurse, Pass the Blowtorch"

Plasma cutters could make surgery less bloody

In medicine, plasma usually refers to the liquid component of blood. Now scientists are researching how to better harness the plasma found in stars and lightning—the fourth fundamental state of matter, alongside solids, liquids and gases—to cut into the body like a blowtorch for bloodless surgery.

Since the early 20th century, surgeons have used sparks of plasma to zap warts and other malignant tissues. Late in that century researchers began investigating how jets of plasma might be used to carve up flesh just as industrial plasma cutters have carved up metal since the 1960s. These plasma scalpels would cauterize flesh as they slice. "It's like a lightsaber," says Washington, D.C., surgeon Jerome Canady, who invented one of the first surgical plasma cutters.

Internal bleeding can be lethal, and finding ways to prevent it can be potentially lifesaving. Minimizing the need for blood transfusions can also be vital, especially on the battlefield—U.S. Special Operations Command field-tested surgical plasma knives in 2008.

A plasma cutter works by streaming pressurized gas such as argon through a narrow channel, where it acquires an electrical charge, transforming it into a blade of plasma traveling more than 1,500 miles per hour. Surgical plasma cutters typically use relatively cold plasmas, hot enough to cauterize tissue on direct contact but only heat surrounding cells to about 97 degrees Fahrenheit. "We can get it more precise than a scalpel blade," Canady says. "You get 0.4 to 0.8 millimeter [0.02 to 0.03 inch] of collateral damage with conventional scalpels, but just 0.1 to 0.2 millimeter [0.004 to 0.008 inch] with plasma cutters."

Increasingly, research suggests that plasma can have therapeutic effects beyond those from heat. Plasma causes the neutrally charged oxygen and nitrogen molecules in the air to become electrically charged. The elements then form ozone, nitrogen oxide and other reactive compounds that can kill off bacteria and cancer cells. Plasma physicist Michael Keidar, director of the George Washington Institute for Nanotechnology in Washington, D.C., and his colleagues have a five-year, $445,000 grant to investigate the physical effects of plasma on the body. Perhaps controlling the frequency, voltage and waveform of the electrical pulses used to energize the plasma affects the depth to which it penetrates living tissue. Such knowledge could help make cuts even more precise and optimize plasma cutting's antibacterial and anticancer effects. "There's been no basic research into this application of plasma," Keidar says. "We hope a full understanding of the mechanisms of what plasma does will open a lot of doors." —*Charles Q. Choi*

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COURTESY OF NORBERT JUERGENS *University of Hamburg*

WHAT IS IT?

Mystery spots: In southwestern Africa's Namib Desert, the lack of rainfall keeps vegetation sparse. Yet in some areas, mysterious rings of grass with bare centers appear and thrive. Now scientists have discovered these so-called fairy circles are indeed created by wee little creatures—termites.

Many organisms live in and around fairy circles, which range from one to 50 meters in diameter and persist for decades. But scientists writing in March in *Science* found only one species consistently inhabiting even the youngest fairy circles—the sand termite *Psammotermes allocerus*—making it the most likely culprit.

How do termites make fairy circles? When termites cluster together, feeding on and destroying vegetation, they leave a roughly circular bare patch that retains more water than the surrounding soil. The fairy circle thus acts as a water reservoir for the sand termites, the grasses around the edge and other thirsty organisms. —*Sophie Bushwick*

BY THE NUMBERS

31 ***Percentage*** of U.S. adults who report having read or sent a text message or e-mail while driving in the past 30 days. The U.S. was tied with Portugal, which had the highest rate in Europe.

15 ***Percentage*** of adults in Spain who report having read or sent a text message or e-mail while driving, the lowest rate in Europe.

ASTROPHYSICS

Closer to Home

A new mission propels detailed investigations of exoplanets

NASA's Kepler mission has been a smash hit. It has discovered thousands of probable exoplanets—worlds orbiting stars other than the sun—more than 100 of which have already been vetted and confirmed. Many of those planets are among the most nearly Earth-size planets known: of the 25 smallest-diameter exoplanets discovered to date, all but one were spotted by Kepler. There is just one asterisk tacked to Kepler's immensely productive haul: the planets are hundreds or even thousands of light-years away, too distant to investigate in any detail.

Enter TESS, the Transiting Exoplanet Survey Satellite, which NASA has green-lit for a 2017 launch at a cost of $200 million. TESS will survey a much larger swath of sky than its predecessor to uncover a new population of nearby exoplanets that scientists can scan with forthcoming telescopes. "Altogether we'll examine about half a million stars," says TESS principal investigator George R. Ricker, a Massachusetts Institute of Technology astrophysicist. Thousands of those stars are within 100 light-years of the solar system.

Like Kepler and the European CoRoT satellite before it, TESS will search for planetary transits: brief dimmings of starlight, occurring at regular intervals, that betray the shadowing presence of an unseen exoplanet. Ricker estimates that TESS may discover some 500 to 700 planets that are Earth-size or a few times larger, of which a handful will be potentially habitable.

Around the time that TESS compiles a list of nearby exoplanets at the end of its two-year baseline mission, astronomers may have a powerful new eye in the sky to examine the newfound worlds in detail. NASA's James Webb Space Telescope (JWST), currently slated to launch in 2018, should be able to tease out the signatures of certain molecules in the atmospheres of nearby planets. Ultimately, those kinds of chemical signatures could be used to infer the presence of extraterrestrial life on a planet. By simulating the observing power of the JWST trained on a nearby, possibly habitable planet, "we can almost see biogenic signatures, but not quite," Ricker says. "That could well take a next-generation space instrument to do that."

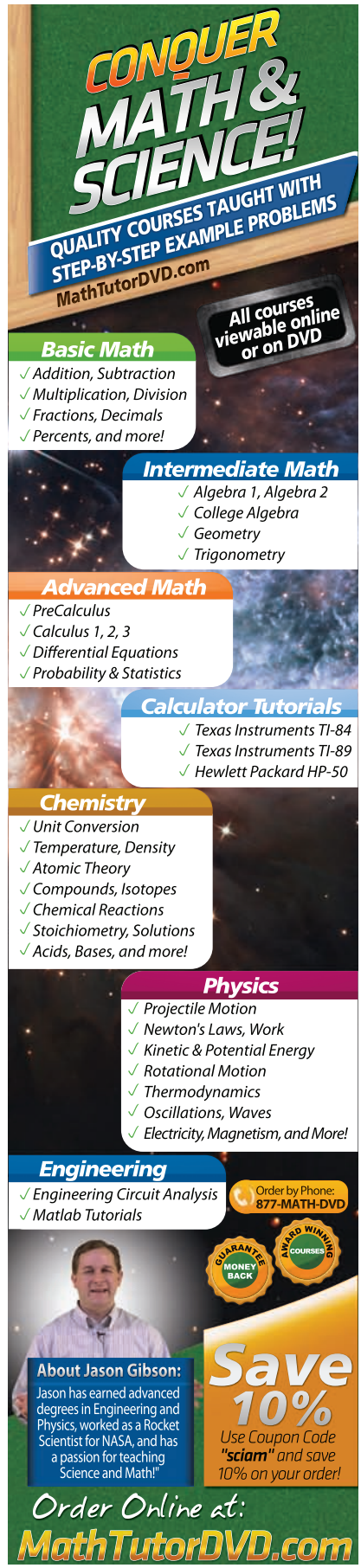
Regardless, if TESS can indeed locate hundreds of nearby planets, astronomers will have their hands full for the foreseeable future—finding out what those planets are like and what kinds of habitats they might support and, just maybe, flinging some future probe toward one enticing-looking world.

—John Matson



Artist's conception of TESS

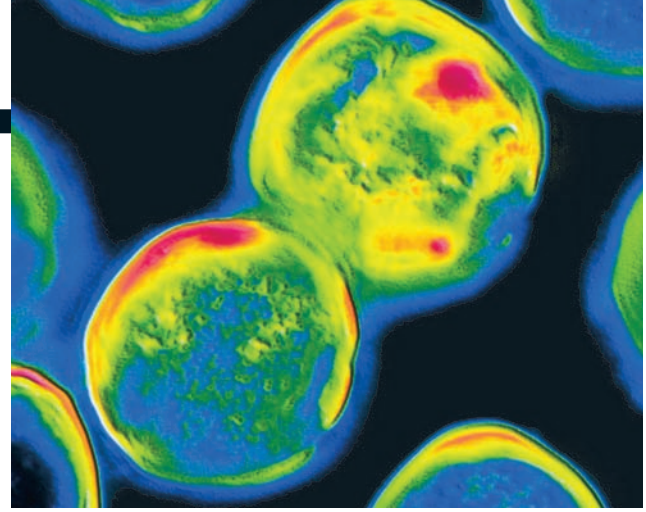
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ASTROBIOLOGY

Running on Poison

Newly discovered microbes breathe rocket fuel



ALFRED PASIEKA *Science Source*

The energetic molecule perchlorate is rocket fuel and, it turns out, food for an ancient kind of life. A team of Dutch researchers show in the April 5 *Science* that the earthly archaeon—as the name implies, an old type of microbe distinct from bacteria—can grow quite happily on perchlorate. *Archaeoglobus fulgidus* (*shown at right*) takes the perchlorate in, gains energy by transforming it into highly reactive chlorite and moves on. Thriving in volcanic vents underneath the sea as well as other superhot areas of Earth, such as oil reservoirs or places where hot rock turns water to steam, *A. fulgidus* and other microbes like it might be the reason there is not more rocket fuel lying around on our planet.

This is the first archaeon known to feed on perchlorate, but it is not the first microbe found to do so. Some bacteria can manage the same trick and even produce a special enzyme to help them rapidly break down the resulting chlorite, which is otherwise damaging to cells, producing oxygen as a by-product. *A. fulgidus,* which cannot tolerate oxygen, uses a different chemistry to break down the chlorite: it relies on sulfur compounds that are naturally present in its environment—a symbiotic relation that exists between life and nonlife chemistries.

A. fulgidus may in fact be a primeval form of life on Earth, having evolved before photosynthesis. Once algae caused the presence of oxygen in the atmosphere to rise, the ancestors of *A. fulgidus* would have had to escape to dark, deep, hot places of the globe. Deposits of perchlorate have also been found wherever robots look on Mars. Does this mean the substance, poisonous to humans, serves as lunch for some Martian microbe?

The prospect is not out of the question. The surface of Mars is certainly too cold for this bug to survive, which may explain why there is so much rocket fuel lying around. But the discovery of the microbe raises the odds that some other life-form on the Red Planet lives deep below the perchlorate-bearing surface.

—David Biello





Going to Pot

As more states make recreational marijuana legal, researchers fret about short- and long-term health effects



Roxanne Khamsi is chief news editor at *Nature Medicine*. She has written for *New Scientist*, the *Economist*, *Wired News* and *MIT Technology Review* and tweets at @rkhamsi

Marijuana is more popular and accessible in the U.S. than any other street drug. In national surveys, 48 percent of Americans say they have tried it, and 6.5 percent of high school seniors admit to daily use. So it was not too surprising when two states, Washington and Colorado, became the first to legalize recreational marijuana in the November 2012 general election, albeit in limited quantity, for anyone over the age of 21. Activists expect that similar measures will soon win approval in other parts of the country.

Some success with medical marijuana helped to pave the road to wider legalization of pot. Eighteen states and the District of Columbia permit possession and consumption of the drug for medical purposes. Doctors in those jurisdictions may prescribe cannabis to treat or manage ailments ranging from glaucoma—an eye disease in which the optic nerve is damaged—to menstrual cramps. Cancer patients sometimes smoke pot to relieve the pain and nausea brought on by chemotherapy, and some people with the inflammatory disease multiple sclerosis rely on marijuana to ease muscle stiffness.

Although many physicians agree that marijuana is safe enough to temporarily alleviate the symptoms of certain medical conditions, the safety of recreational use is poorly understood. Researchers worry that both the short- and long-term use of the drug may harm the body and mind. Marijuana's continued popularity among teenagers raises particular concern because the drug might hinder the ongoing maturation of the adolescent brain. Making matters worse, new growing techniques for the *Cannabis sativa* plant—from which marijuana is prepared—have dramatically increased the drug's potency. Some experts suggest that such high-octane weed is fueling a rise in cannabis addiction. Finally, although investigators still debate how the legalization of recreational marijuana will change road safety overall, studies indicate that the drug slows reaction time and impairs distance perception behind the wheel. Despite such evidence, most new marijuana regulations, for medical or recreational use, fail to account for these potential risks.

WEEDED OUT

WHETHER ROLLED into a joint or mixed into brownie batter, marijuana profoundly changes behavior and awareness. The primary psychoactive compound in marijuana, tetrahydrocannabinol (THC), mimics the structure of molecules called endocannabinoids that the human body produces naturally. Endocannabinoids act on a group of cell-surface molecules called cannabinoid receptors that help to regulate appetite, mood and memory. Because of its shape, THC fits into these receptors, too. After all, jokes neuroscientist Giovanni Marsicano of the University of Bordeaux in France, "We don't have a receptor in the body just to smoke marijuana."

When THC strikes specific cannabinoid receptors, it triggers domino chains of interacting molecules in neurons that culminate in both unusually elevated and abnormally low levels of various neurotransmitters (the molecules that brain cells use to communicate with one another). The result is the well-known "high" of marijuana. Suddenly, the mundane seems hilarious, and ordinary foods taste delicious. People generally feel merry, relaxed and introspective, although undesirable effects—such as paranoia and irritability—are common as well.

Marijuana also temporarily impairs an array of mental abilities, especially memory and attention. Dozens of studies have shown, for example, that people under the influence of marijuana perform worse on tests of working memory, which is the

GETTY IMAGES

ability to temporarily hold and manipulate information in one's mind. Participants in these studies have greater difficulty remembering and reciting short lists of numerals and random words. Research has further revealed that cannabis blunts concentration, weakens motor coordination and interferes with the ability to quickly scan one's surroundings for obstacles.

Such mild cognitive deficits may not endanger anyone if a marijuana user lazes on the couch, but it is a different story when someone takes that high on the road. In driving-simulation and closed-course studies, people on marijuana are slower to hit the brakes and worse at safely changing lanes. Investigators still debate, however, at what point these impairments translate to more traffic accidents. A 2009 study found an increased risk of accidents for levels of THC higher than five nanograms per milliliter of blood, which some evidence indicates is as impairing as a blood alcohol concentration around the legal limit of 0.08 percent. Typically one would have to take several puffs of a joint to reach such a concentration. Consequently, voters in Washington State have adopted 5 ng/mL as the upper threshold for drivers.

Enforcing that limit presents a technical challenge, however. Unlike alcohol, marijuana cannot be detected with a relatively unobtrusive Breathalyzer test. Police officers would have to look for it in blood—something that often requires a warrant. "There is currently no practical method for law-enforcement officers at the scene to collect blood samples from suspected DUI cannabis drivers in a timely manner," says Paul Armentano, deputy director of the Washington, D.C.–based National Organization for the Reform of Marijuana Laws, which advocates the legalization of marijuana. Instead of using a blood test, Armentano says that police should look for poor maneuvering and the smell of pot wafting from the vehicle.

An All-Time High

Eighteen states and the District of Columbia have legalized medical marijuana (*blue*). Last year two states legalized recreational marijuana (*red*).



- Connecticut, 2012
- Massachusetts, 2012
- Delaware, 2011
- Arizona, 2010
- Washington, D.C., 2010
- New Jersey, 2010
- Michigan, 2008
- New Mexico, 2007
- Rhode Island, 2007
- Montana, 2004
- Vermont, 2004
- Colorado, 2000, 2012
- Hawaii, 2000
- Nevada, 2000
- Maine, 1999
- Alaska, 1998
- Oregon, 1998
- Washington State, 1998, 2012
- California, 1996

SMOKE SIGNALS

ALTHOUGH MARIJUANA'S immediate effects are relatively easy to monitor in the lab, the drug's long-term effects on body and mind are harder to determine. So far the results—which admittedly are subject to multiple interpretations—indicate the need for caution. In one recent study, clinical psychologist Madeline Meier of Duke University and her colleagues examined data from 1,037 New Zealanders. They found that people who began using pot earlier in life and used it most frequently over the years experienced an average decline of eight IQ points by the time they turned 38. By comparison, those who never smoked pot had an average increase of one IQ point by the same age.

A reanalysis of the New Zealand data by Ole Røgeberg of the Ragnar Frisch Center for Economic Research in Oslo, however, suggested that the IQ difference could be explained by socioeconomic factors. People who start smoking marijuana at an earlier age are often less intelligent to begin with. Even if this is true, Meier says, her study shows that the IQ drop is greatest for those who started smoking pot as teenagers rather than in adulthood, indicating a worrisome cumulative effect regardless of intelligence. This finding, she thinks, makes it all the more important to discourage the early use of marijuana among teens.

Increasingly potent marijuana of recent years may be driving a sharp rise in cannabis addiction among adolescents, according to a report released last year by the American Society of Addiction Medicine. Between 1993 and 2008, the average concentration of THC in confiscated marijuana jumped from 3.4 to 8.8 percent. Meanwhile hospital and rehabilitation center admission rates for minors abusing marijuana soared by 188 percent between 1992 and 2006. In contrast, admissions for alcohol abuse for the same group over the same period declined by 64 percent.

In addition to tracking levels of THC itself, some researchers have focused on the dangers of lingering contaminants in marijuana sold on the street. Dealers typically sell cannabis by weight, so some use sand or glass beads to make their products heavier. Breathing in these particles over the years may inflame and eventually scar the lungs. An analysis published last year of data on more than 5,000 Americans did not find a decline in lung function among individuals who smoked joints two or three times a month over two decades. The authors emphasize, however, that they did not assess the effect of daily use on lung health. "Somebody should do that study if marijuana is going to become legalized and prescribed" more widely, says Mark Pletcher, an epidemiologist at the University of California, San Francisco, who co-wrote the paper.

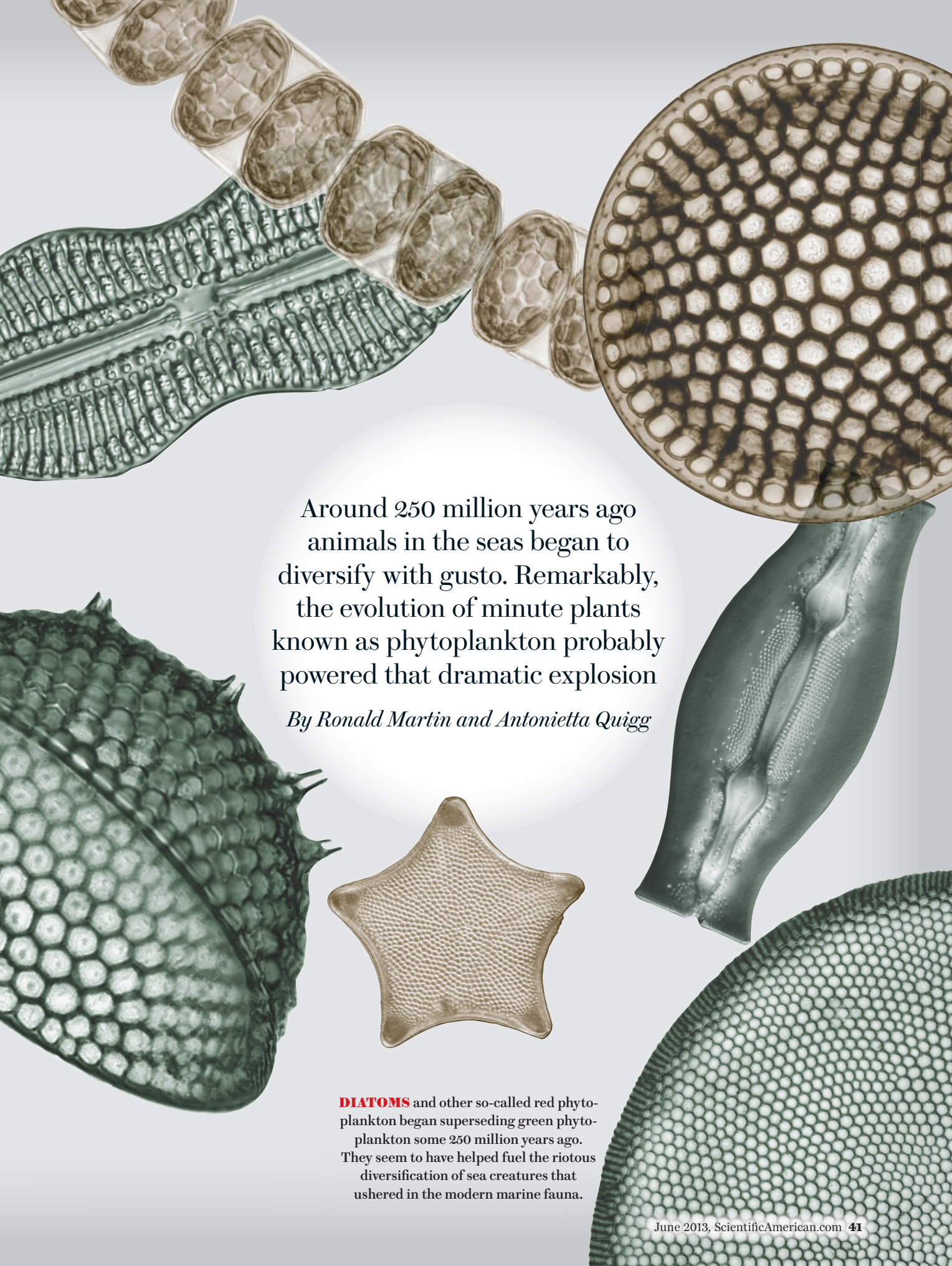
Some opponents of legalization worry that lax regulation of medical marijuana foretells even looser laws concerning recreational marijuana. In states that have legalized medical pot, current laws do not guarantee the safety or quality of cannabis products or standardize levels of THC. In Oakland, Calif., people can fill a marijuana prescription at Harborside Health Center, a massive dispensary with a strict quality-control system. Elsewhere in the state, however, people get their medical marijuana at mom-and-pop outfits or on the street. The next big round of ballot initiatives to legalize cannabis in states other than Washington and Colorado could happen as soon as three years from now, in the 2016 presidential election. Until then, researchers have plenty of marijuana health risks to weed through. SA

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LIFE SCIENCE

Tiny Plants That Once Ruled the Seas



Around 250 million years ago animals in the seas began to diversify with gusto. Remarkably, the evolution of minute plants known as phytoplankton probably powered that dramatic explosion

By Ronald Martin and Antonietta Quigg

DIATOMS and other so-called red phytoplankton began superseding green phytoplankton some 250 million years ago. They seem to have helped fuel the riotous diversification of sea creatures that ushered in the modern marine fauna.

Ronald Martin is a professor of geology at the University of Delaware. His research focuses on the evolution of ecosystems and biogeochemical cycles.



Antonietta Quigg is a professor of marine biology at Texas A&M University at Galveston, where she studies phytoplankton ecology and physiology.



IF YOU COULD HOP ONBOARD A TIME MACHINE AND VISIT THE EARTH as it was 500 million years ago, during the Paleozoic era, you'd be forgiven for thinking you had traveled not to another time period but to another planet altogether. In essence, you would have. The continents mostly sat in the Southern Hemisphere, the oceans had vastly different configurations and currents, the Alps and the Sahara had yet to form. Land plants had not even evolved. Perhaps the most dramatic difference, however, would lie in the animals that inhabited this primeval earth. Back then, most of the world's multicellular creatures lived in the sea. Clamlike creatures called brachiopods and trilobites—those extinct cousins of today's lobsters and insects, with their hard exoskeletons, long antennae and compound eyes—reigned supreme.

The diversity of marine animals grew substantially over the next 250 million years, until the so-called Permian extinction event snuffed out more than 90 percent of ocean species and brought the Paleozoic to a close. The loss of life was staggering. But change was on the horizon, and while life on land underwent a radical transformation with the rise of dinosaurs and mammals, life in the sea entered a dramatic phase of reorganization that would establish the dominance of many of the animal groups that prevail in the marine realm today, including modern groups of predatory fish, mollusks, crustaceans, sea urchins and sand dollars, among others.

The fossil record shows that over the ensuing Mesozoic and Cenozoic eras, marine life diversified at an unprecedented rate—so much so that scientists once questioned whether the pattern merely reflected the preferential preservation of geologically younger fossils, which have had less time to undergo erosion. Subsequent analyses indicated that this apparent florescence of species in the sea was indeed real, however. To explain the phenomenon, researchers have turned to a range of factors, including changes in climate and sea level, as well as mass extinctions, all of which could have fostered new opportunities. Yet although all these events may have contributed to the diversification that began around 250 million years ago, they cannot alone account for the pattern of the observed explosion.

There is another, underappreciated factor to consider: food availability. It turns out that increases in the quantity and nutrient content of microscopic plants known as phytoplankton, which form the base of marine food pyramids, accompanied the stunning emergence of new sea creatures in the Mesozoic and Cenozoic. We submit that the evolution of these modest plants fueled the rise of the modern marine fauna. This novel understanding of how phytoplankton transformed life in the ancient seas has something to say about the future of our planet as well. Phytoplankton continue to support food pyramids today; however, if future climate change and deforestation disrupt controls on their proliferation, as they have already begun to do, these plants could become a force of destruction.

FUEL CELLS

TO UNDERSTAND THE VITAL ROLE phytoplankton have played in the evolution of marine animals, it helps to know a bit about their biology and their relation to the microscopic animals that feed on them. Like all plants, phytoplankton convert the sun's energy into food through photosynthesis. Tiny, drifting herbivores collectively known as zooplankton then eat the phytoplankton and are themselves eaten by consumers higher up in the food pyramid. Nitrogen, iron, phosphorus and other nutrients in the water act like fertilizer to stimulate phytoplankton growth. The greater the availability of these nutrients, the more phytoplankton can

IN BRIEF

After a mass extinction 250 million years ago decimated marine life, sea creatures began diversifying like crazy.

Scientists traditionally chalked this evolutionary explosion up to physical factors, such as changing sea levels.

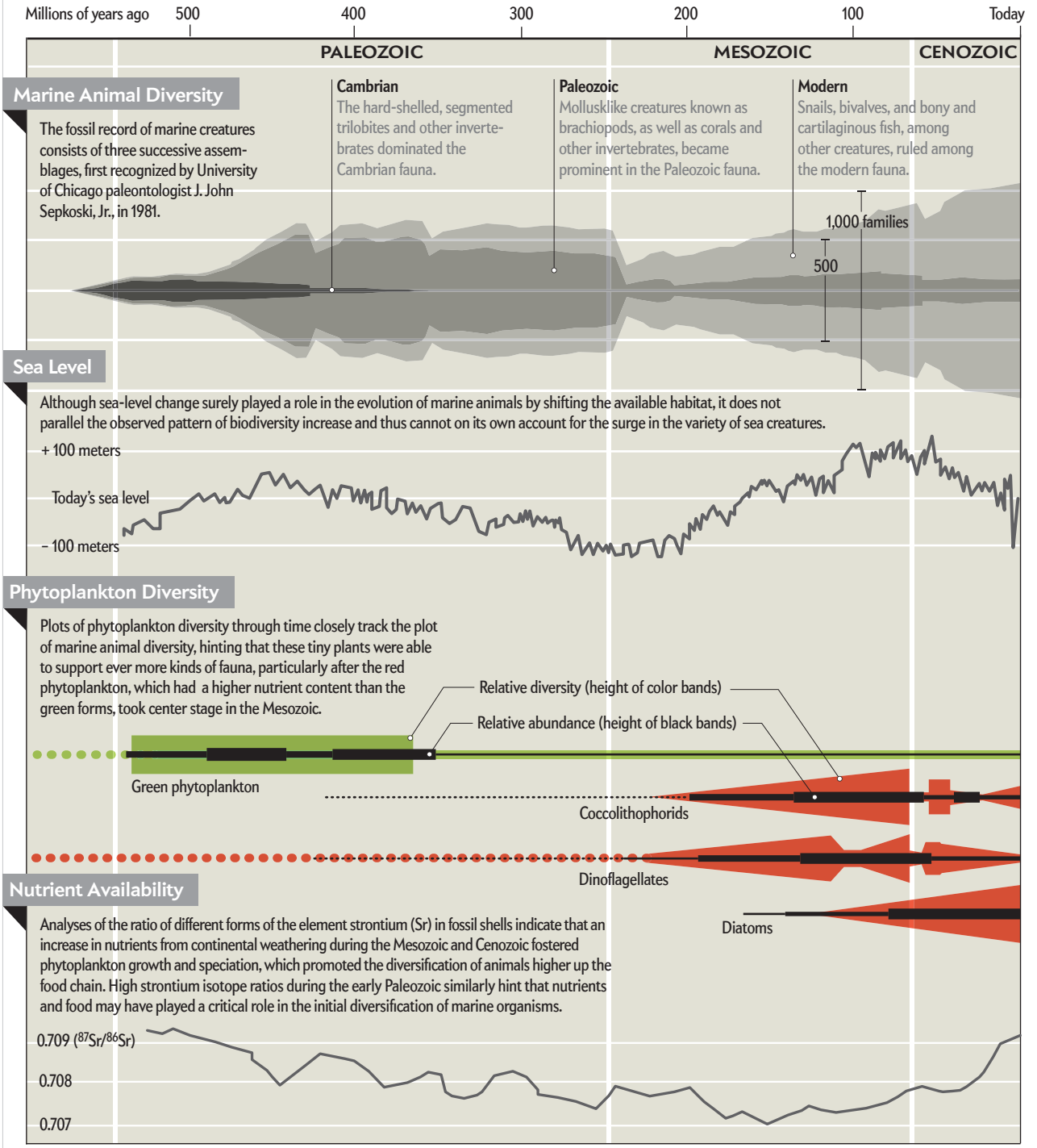
But mounting evidence suggests that the role of tiny aquatic plants known as phytoplankton has been overlooked.

Increases in the quantity and quality of phytoplankton seem to have fueled the rise of the modern marine animal groups.

PRECEDING PAGES: CHARLES KREBS

The Phytoplankton Effect

A mass extinction at the end of the Paleozoic era, around 250 million years ago, claimed more than 90 percent of marine species. But in the Mesozoic and Cenozoic eras that followed, ocean-dwelling animals staged a major comeback, reaching far higher levels of diversity than ever before. Scientists have traditionally attributed this explosion to physical factors such as sea-level change. Mounting evidence suggests, however, that the evolution of phytoplankton—the tiny plants that form the base of marine food chains—played a previously underappreciated role in fueling the florescence of animal life in the seas.



SOURCE: "EVOLVING PHYTOPLANKTON STOICHIOMETRY FUELED DIVERSIFICATION OF THE MARINE BIOSPHERE," BY RONALD MARTIN AND ANTONIETTA QUIGG, IN *GEOSCIENCES*, VOL. 2, NO. 2, JUNE 2012

Graphic by Jen Christiansen

grow and the more zooplankton eat them and keep proliferating.

In addition to boosting phytoplankton numbers, an abundance of nutrients can make phytoplankton more nutritious for zooplankton—more stuffed with readily available fuel and thus better able to support the maintenance, growth and reproduction of the minuscule animals. As populations grow, they spread out, spawn new populations that become isolated from their forebears, adapt to new circumstances and form new species.

One of the first hints that a bump in phytoplankton abundance might have had a part in triggering life's explosion after the Paleozoic came in the 1990s. Researchers, including Richard Bambach, now at the Smithsonian Institution, and one of us (Martin), independently inferred from the fossil record of marine animals that food availability must have increased from the Paleozoic to the Cenozoic. They drew that conclusion because predators and other species that have higher energy requirements than zooplankton made up an increasing proportion of marine life over time. More recently, the two of us (Martin and Quigg), along with Victor Podkovyrov of the Russian Academy of Sciences, have found evidence in the fossil record of marine plankton to support that conclusion.

We have discovered that back in the Paleozoic, enigmatic phytoplankton grouped under the informal name of green algae, formed the base of marine food pyramids, and predators were relatively rare. But after the Permian mass extinction wiped out the vast majority of marine life, including most of the green algae, new kinds of phytoplankton appeared, starting with coccolithophores, so named for the calcium carbonate shells, or "coccoliths," they secrete, possibly for protection. These distinctive plants were soon joined by the dinoflagellates and diatoms, which would go on to become the most diverse and abundant phytoplankton in the oceans. These three groups—dubbed red algae because of the type of chlorophyll they use in photosynthesis—largely replaced the green algae of the Paleozoic, setting the stage for the emergence of animal species that could exploit this new bounty.

The realization that red algae were so key made us wonder what allowed them to prevail over the green forms that survived the mass extinction. Shifts in the availability of micronutrients (nutrients available in low concentrations) used in photosynthesis appear to have played an important role. Studies of the micronutrient content of modern green and red algae, conducted by Quigg and her colleagues at Rutgers University, suggest that, as is true today, green algae had higher concentrations of iron, zinc and copper than their red counterparts, whereas red forms had higher amounts of manganese, cobalt and cadmium. Those differences mean that the micronutrients needed by the red algae must have become more abundant than those needed by the green algae.

Geologic evidence supports this notion. The abundance of carbon-rich rock known as black shale dating to the Paleozoic indicates that oxygen levels in the oceans must have been low back then because exposure to higher levels of oxygen would have caused the carbon to decay. Under these low-oxygen conditions, iron and the other micronutrients green phytoplankton thrive on would have dissolved more easily in the ocean and thus been more readily available for use in photosynthesis. In contrast, black shales from the Mesozoic are much rarer, restricted to brief periods when the seas became depleted of oxygen. The relative rarity of Mesozoic black shales implies that, on the whole, oxygen levels were much higher in that era. These conditions would have helped the micronutrients used by the red phytoplankton to remain dissolved in the oceans and available for uptake.

GREEN VS. RED

BUT SHIFTS IN THE AVAILABILITY of micronutrients during the Mesozoic do not fully account for the red algae's rise to dominance. We propose that changes in the availability of macronutrients (nutrients available in higher concentrations), such as phosphorus, also contributed significantly to the success of these groups. And these macronutrients, which phytoplankton use in such fundamental biochemical processes as DNA synthesis, appear to have entered the seas as a result of events taking place on terra firma.

By the later Paleozoic and Mesozoic, forests were spreading on land, and climate was becoming more humid, elevating weathering rates on the continents. Increased physical and chemical weathering resulting from tree roots breaking up the earth, leaves decaying and soil forming would have promoted the runoff of nutrients from the land and dead plants into the shallow inland seaways where plankton thrived. The emergence of flowering plants during the Mesozoic would have added to this runoff because their leaf litter decays much more rapidly than that of conifers, cycads and other trees that formed the earliest forests.

Evidence of continental weathering comes from analyses of the ratio of different forms of the element strontium found in fossil shells. Because continental rocks are enriched in strontium 87 as compared with oceanic rocks, the observed increase in the ratio of strontium 87 to strontium 86 in the shells over time indicates nutrients were flowing from land into the ocean in ever greater amounts, as would be expected if continental weathering were taking place. Similar isotope studies conducted using another element, lithium, confirm the trend.

Isotope studies not only confirm the existence of such fluxes from land, they also lend credence to the idea—first proposed by Martin in 1996—that nutrient runoff from continental weathering could increase marine biodiversity both in phytoplankton and in the animals that eat them. If nutrient input from land was in fact critical to the diversification of plankton, and thus other creatures, during the Mesozoic and Cenozoic, one would expect rises in the ratio of strontium 87 to strontium 86 in the shells to parallel increases in the diversity of marine creatures over time. Indeed, recent plots of strontium ratios do march in step with a diversity curve developed by John Alroy of Macquarie University in Australia in 2010. Another study published that same year, by Andrés Cárdenas and Peter Harries of the University of South Florida, found a similar correlation.

Higher oxygen levels in the oceans and the spread of forests and flowering plants on land would not have been the only factors acting to enhance the availability of nutrients to phytoplankton. Widespread mountain building that occurred as continental collisions formed the supercontinent Pangaea, along with the falling sea levels of the era, would have begun to increase the rates of weathering and nutrient runoff into the seas before the Mesozoic. And the continental glaciers that occupied the Southern Hemisphere during most of the later Paleozoic would have promoted relatively rapid circulation and oxygenation of the oceans, together with the upwelling of waters already enriched in phosphorus from the decay of organic matter and oxygen-sensitive trace metals. All told, these factors would have created

favorable conditions for the red algae to flourish, providing them with plenty of the exact kinds of micronutrients and macronutrients they were best suited to exploit.

The reign of the nutrient-poor green algal lineages during the first half of the Paleozoic seems to have kept the evolution of marine animals in check, delaying the appearance of new forms with higher metabolic rates. But as the nutrient-rich red algae took center stage, the marine animals that ate these phytoplankton underwent dramatic diversification, as the fossil record shows. Novel groups of predatory fish burst onto the evolutionary scene, along with new varieties of mollusks, crustaceans, corals and bivalves, among other animals.

Two recent field experiments offer a proof of principle that the kind of nutrient runoff we have described could have sparked diversification of multicellular animals. In the first, Tron Frede Thingstad of the University of Bergen in Norway and his colleagues added phosphorus to surface waters of the eastern Mediterranean Sea, which are naturally extremely poor in nutrients generally and starved of phosphorus specifically. These waters resemble the conditions that Martin postulated to exist early in the Paleozoic. The experimental nutrient input stimulated rapid uptake of the phosphorus by local phytoplankton—much more than required for normal growth—thus enriching the nutrient content of the tiny plants within little more than a week.

In the second experiment, James Elser of Arizona State University added phosphorus to communities of so-called cyanobacteria in a stream in Coahuila, Mexico. These cyanobacteria obtained their food through photosynthesis the way plants do and were similar to cyanobacteria that lived during the early Paleozoic. The extra phosphorus lowered the ratios of carbon (a nonnutrient) to phosphorus in these communities from as much as 1,100:1 down to 150:1, at which point the growth rate, the total amount of living tissue and the survivorship of the snails grazing on the cyanobacteria all markedly increased.

Although these experiments did not demonstrate evolutionary diversification (because of their short duration), they show that increased availability of key nutrients in the seas could have quickly raised the nutrient content of phytoplankton and that enriched phytoplankton could have in short order passed these benefits up the food chain to the animals that ate them, freeing those animals up to devote more energy to reproduction, which is a prerequisite to diversification.

RETURN TO THE PALEOZOIC

UNDERSTANDING HOW PHYTOPLANKTON responded to shifting environmental conditions in the past could help scientists predict what the future holds for marine life in our changing world. Carbon dioxide emitted as a result of human activities is both heating the earth and acidifying the sea. In coming centuries, the oceans will, to a certain extent, come to resemble those of the Mesozoic or Paleozoic. In the deep ocean, thick calcium carbonate–rich deposits formed from the accumulation of sunken coccolithophore shells will tend to neutralize the dissolved carbon dioxide. But in the surface waters, the coccolithophores and other calcifying phytoplankton that live there may be devastated by the acidification, which reduces the availability of minerals needed to make and maintain their shells. Although such organisms have endured environmental change for hundreds of millions of years, the current influx of carbon dioxide is happening so quickly that they may not be able to adapt to it fast enough.

The loss of these organisms could exacerbate warming. Today blooms of the coccolithophore *Emiliania huxleyi* can cover areas greater than 100,000 square kilometers, and they produce significant amounts of the compound dimethyl sulfide, which, in turn, seeds cloud formation. And clouds reflect sunlight back into space, cooling the planet. Without coccolithophores, then, the earth would absorb more solar energy than it already does.

Calcifying phytoplankton that live in reef communities will suffer a double whammy from anthropogenic CO_2. Not only will acidification dissolve their skeletons, but warming will quickly surpass the limits of their temperature tolerance (reef species tend to live near the upper limits of their temperature tolerance).

Carbon dioxide emissions are not the only threat humans pose to phytoplankton. Soil erosion from deforestation and other human activities are flooding coastal systems—where reef species thrive—with nutrients, leading to excessive growth, and subsequent decay, of aquatic plants. Reefs will be devastated by the invasion of new species that will outcompete the slower-growing reef forms. Although nutrient inputs to the ocean fueled the diversification of life over hundreds of millions of years, the current pace of "enrichment" is clearly too much of a good thing.

As the oceans warm, they may also become increasingly stratified: warm water acts as a lid on the cold water, thus impeding upwelling and circulation. Dinoflagellates dominate under such conditions, which could increase the frequency and surface area covered by toxic blooms in coastal habitats. Because these habitats also serve as refueling stops for migratory birds and nurseries for commercially important fish and crustaceans, we humans will feel the effects of their degradation acutely.

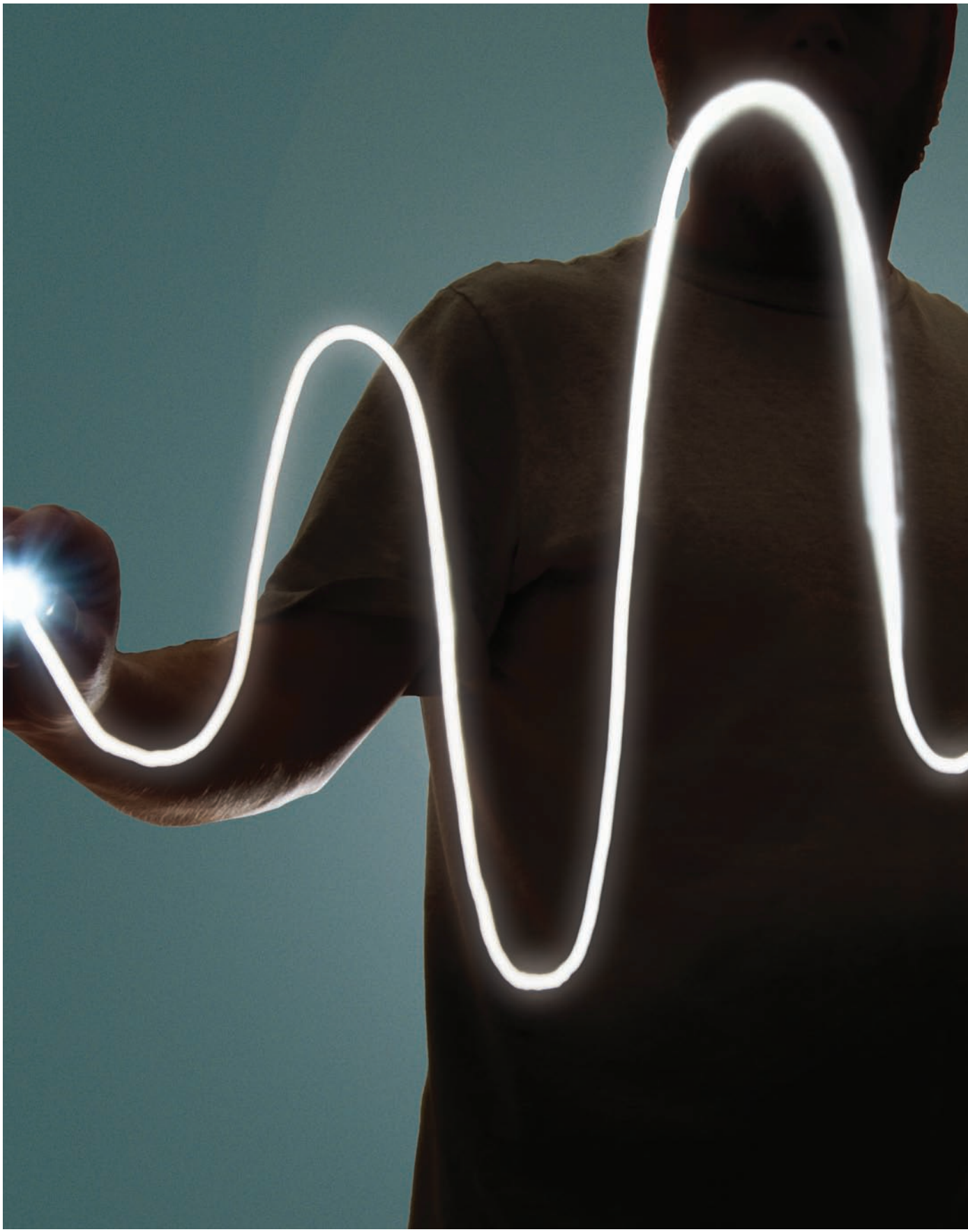
Future studies will flesh out scientists' understanding of how environmental change affected the evolution of phytoplankton in the past and how the rise of the red forms spurred the diversification of marine animals. We are eager to determine, for example, how the low oxygen conditions of areas such as the Mississippi Delta affect nutrient uptake by phytoplankton and how this shift in nutrient uptake affects the community of animals that feed on them. Similar studies have been conducted in lake settings, in which the community structure is rapidly altered via domino effects.

Such findings may help researchers better predict how modern phytoplankton—and the species that depend on them—will fare in the future. But one thing is clear. Although deniers of climate change often argue that life on earth routinely adapted to environmental shifts in the past and can thus handle future fluctuations, this is the wrong way to think about our current situation. Human activities are altering ocean conditions at a speed unsurpassed in our earth's history. We are thus unwittingly conducting an experiment that has never been run on this planet, the exact outcome of which will not be known until it has occurred. SA

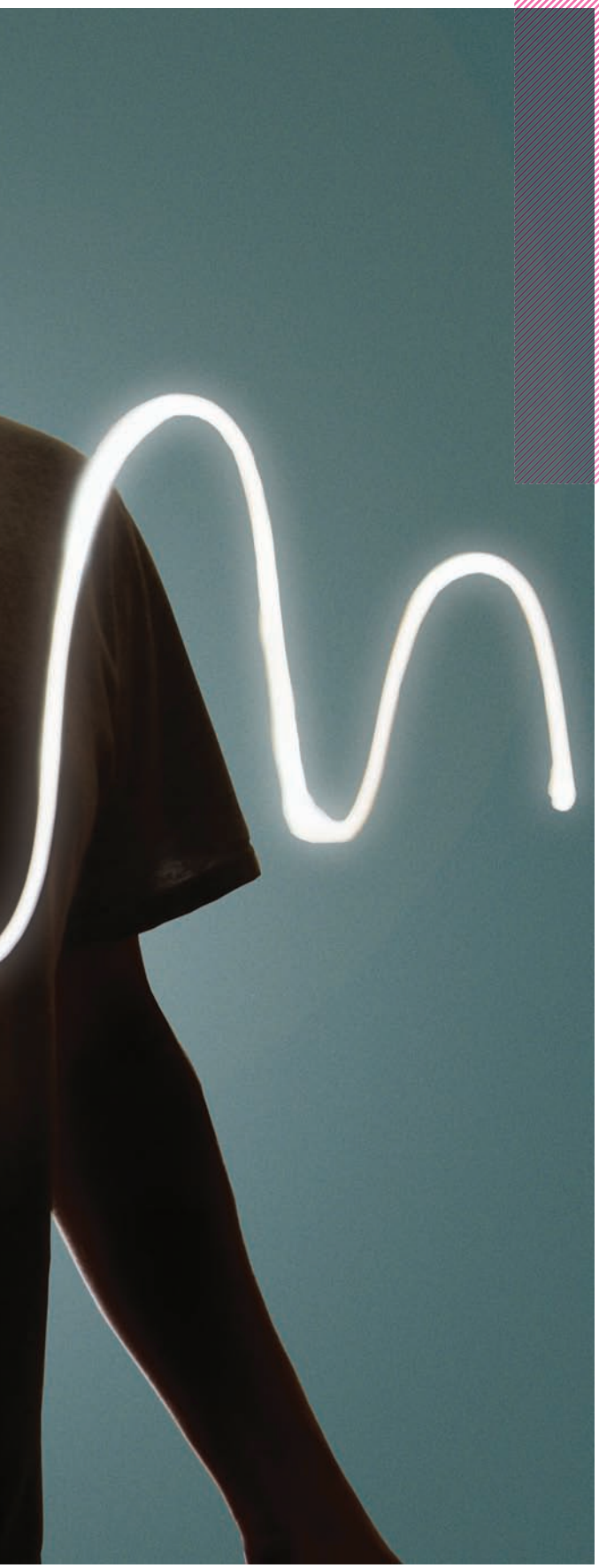
MORE TO EXPLORE

Evolving Phytoplankton Stoichiometry Fueled Diversification of the Marine Biosphere. Ronald Martin and Antonietta Quigg in *Geosciences*, Vol. 2, No. 2, pages 130–146; June 2012.

SCIENTIFIC AMERICAN ONLINE
View a slide show of phytoplankton at ScientificAmerican.com/jun2013/phytoplankton



Photograph by Caleb Charland



PHYSICS

QUANTUM WEIRDNESS? *IT'S ALL IN YOUR MIND*

A new version of quantum theory sweeps away the bizarre paradoxes of the microscopic world. The cost? Quantum information exists only in your imagination

By Hans Christian von Baeyer

FLAWLESSLY ACCOUNTING FOR THE BEHAVIOR OF MATTER ON scales from the subatomic to the astronomical, quantum mechanics is the most successful theory in all the physical sciences. It is also the weirdest.

In the quantum realm, particles seem to be in two places at once, information appears to travel faster than the speed of light, and cats can be dead and alive at the same time. Physicists have grappled with the quantum world's apparent paradoxes for nine decades, with little to show for their struggles. Unlike evolution and cosmology, whose truths have been incorporated into the general intellectual landscape, quantum theory is still considered (even by many physicists) to be a bizarre anomaly, a powerful recipe book for building gadgets but good for little else. The deep confusion about the meaning of quantum theory will continue to add

fuel to the perception that the deep things it is so urgently trying to tell us about our world are irrelevant to everyday life and too weird to matter.

In 2001 a team of researchers began to develop a model that either eliminates the quantum paradoxes or puts them in a less troubling form. The model, known as Quantum Bayesianism, or QBism for short, reimagines the entity that lies at the heart of quantum weirdness—the wave function.

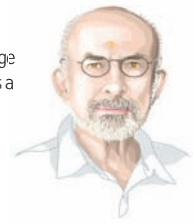
In the conventional view of quantum theory, an object such as an electron is represented by its wave function, a mathematical expression that describes the object's properties. If you want to predict how the electron will behave, you calculate how its wave function evolves in time. The result of the calculation gives you the probability that the electron will have a certain property (like being in one place and not another). But problems arise when physicists assume that a wave function is real.

QBism, which combines quantum theory with probability theory, maintains that the wave function has no objective reality. Instead QBism portrays the wave function as a user's manual, a mathematical tool that an observer uses to make wiser decisions about the surrounding world—the quantum world. Specifically, the observer employs the wave function to assign his or her personal belief that a quantum system will have a specific property, realizing that the individual's own choices and actions affect the system in an inherently uncertain way. Another observer, using a wave function that describes the world as the person sees it, may come to a completely different conclusion about the same quantum system. One system—one event—can have as many different wave functions as there are observers. After observers have communicated with one another and modified their private wave functions to account for the newly acquired knowledge, a coherent worldview emerges.

Seen this way, the wave function "may well be the most powerful abstraction we have ever found," says theoretical physicist N. David Mermin of Cornell University, a recent convert to QBism.

THE UNREAL QUANTUM

THE NOTION that the wave function isn't real dates back to the 1930s and the writings of Niels Bohr, one of the founding fathers of quantum mechanics. He considered it part of quantum theory's "purely symbolic" formalism—a computational tool, no more. QBism is the first model to give mathematical backbone to Bohr's assertion. It melds quantum theory with Bayesian statistics, a 200-year-old discipline that defines "probability" as something like "subjective belief." Bayesian statistics also gives formal mathematical rules for how to update one's subjective beliefs in light of new information. By interpreting the wave function as a subjective belief and subject to revision by the rules of Bayesian statistics, the mysterious paradoxes of quantum mechanics vanish, QBism's proponents say.



Hans Christian von Baeyer is a theoretical particle physicist and Chancellor Professor emeritus at the College of William and Mary, where he taught for 38 years. He is a fellow of the American Physical Society, author of six popular science books, and the recipient of the Science Writing Award of the American Institute of Physics (twice), a Westinghouse AAAS Writing Award, and a National Magazine Award for essays and criticism.

Consider again the electron. We know that each time we detect an electron, we find it in one particular location. But when we're not looking, the electron's wave function can spread out, representing the possibility that the electron is in many different places at once. Now make a measurement again. You'll find the electron back in a particular location. According to the standard way of thinking, the observation causes the wave function to instantaneously "collapse" back to a single particular value.

Because the collapse happens everywhere at exactly the same time, it seems to violate the principle of locality—the idea that any change in an object must be caused by another object in its immediate surroundings. This, in turn, leads to some of the puzzles that Albert Einstein called "spooky action at a distance."

From the very birth of quantum mechanics, physicists saw the collapse of the wave function as a paradoxical and deeply disturbing feature of the theory. Its uneasy mysteries pushed physicists to develop alternative versions of quantum mechanics, with mixed success [*see box on page 50*].

Yet QBism says that there is no paradox. The wave function's collapse is just an observer suddenly and discontinuously revising his or her probability assignments based on new information, in the same way that a doctor would revise a cancer patient's prognosis based on a new CT scan. The quantum system hasn't undergone some strange and inexplicable change; the change is in the wave function, which is chosen by the observer to encapsulate the person's expectations.

We can apply this way of thinking to the famous paradox of Schrödinger's cat. Quantum physicist Erwin Schrödinger imagined a sealed box with a live cat, a vial of poison and a radioactive atom. The atom has a 50–50 chance of decaying within an hour, according to the rules of quantum mechanics. If the atom decays, a hammer will smash the vial and release the poison, killing the cat. If it doesn't, the cat lives.

Now run the experiment—but don't look inside the box. After an hour has gone by, traditional quantum theory would hold that the atom's wave function is in a superposition of two states—decayed and not decayed. But because you haven't yet observed what is inside the box, the superposition extends further. The

IN BRIEF

Quantum mechanics is an incredibly successful theory but one full of strange paradoxes. A recently developed model called Quantum Bayesianism (or QBism) combines quantum theory with probability theory in an effort to eliminate the paradoxes or put them in a less troubling form.

QBism reimagines the entity at the heart of quantum paradoxes—the wave function. Scientists use wave functions to calculate the probability that a particle will have a certain property, such as being in one place and not another. But paradoxes arise when physicists assume that a wave function is real.

QBism maintains that the wave function is solely a mathematical tool that an observer uses to assign his or her personal belief that a quantum system will have a specific property. In this conception, the wave function does not exist in the world—rather it merely reflects an individual's subjective mental state.

hammer is also in a superposition, as is the vial of poison. And most grotesquely, the standard quantum-mechanical formalism implies that the cat is in a superposition—it is both alive and dead at the same time.

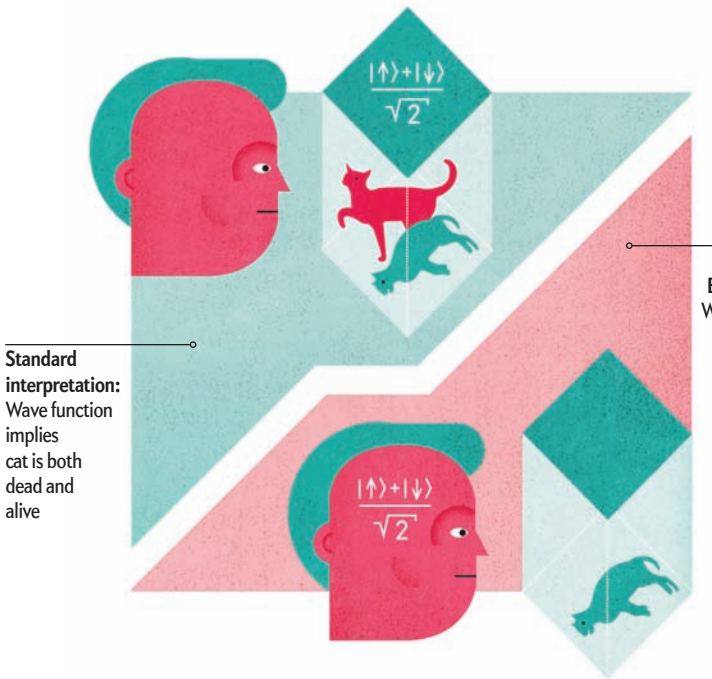
By insisting that the wave function is a subjective property of the observer, rather than an objective property of the cat in the box, QBism eliminates the puzzle. The theory says that *of course* the cat is either alive or dead (and not both). Sure, its wave function represents a superposition of *alive* and *dead,* but a wave function is just a description of the observer's beliefs. Asserting that the cat is truly both alive and dead is akin to a baseball fan saying that the Yankees are stuck in a superposition of both *won* and *lost* until he reads the box score. It's an absurdity, a megalomaniac's delusion that one's personal state of mind makes the world come into being.

The hope is that by removing the paradoxes, QBism will help physicists home in on the truly fundamental features of quantum theory—whatever they turn out to be—and "prevent them from wasting their time asking silly questions about illusory puzzles," Mermin says.

THOUGHT EXPERIMENT

The Fix for Quantum Absurdity

To explore the difference between Quantum Bayesianism and the standard interpretation of quantum mechanics, consider the famous example of Schrödinger's cat. In the standard telling, a cat and a vial of poison are sealed in a box. A quantum event that happens with a probability of 50 percent breaks (or does not break) the vial and kills (or does not kill) the cat. Before an observer looks inside the box, the wave function describing the system is in a superposition of both "alive" and "dead" states, as is the cat itself. The observation collapses the cat into one state or another. In QBism, by contrast, the wave function is merely a description of the observer's mental state. The superposition applies to this state, nothing more. The cat is either alive or dead; the observation reveals which.



Standard interpretation: Wave function implies cat is both dead and alive

Quantum Bayesianism: Wave function describes mental state only; cat is either dead or alive

THE TROUBLEMAKER

QBISM WAS BORN in a short paper published in January 2002 under the title "Quantum Probabilities as Bayesian Probabilities," by Carlton M. Caves of the University of New Mexico, Christopher A. Fuchs, then at Bell Labs in Murray Hill, N.J., and Ruediger Schack of the University of London. All three are experienced quantum information theorists, and their respective affiliations with a physics department, an industrial laboratory and a department of mathematics illustrate the interdisciplinary nature of their field.

In the intervening decade Fuchs moved to the Perimeter Institute in Ontario and assumed the role of QBism's chief spokesperson. He is a compact Texan with a cheerful disposition and a genial manner. A sandy-colored cowlick at his hairline hints at his irrepressible, irreverent sense of humor. Colleagues are not surprised when he opens an article with the words "In this paper, I try to cause some good-natured trouble."

The core of Fuchs's style is the conviction that science is quintessentially a communal activity and that profound insight is won only through vigorous intellectual combat. He is a whirlwind of activity, lugging his laptop around the world in a beat-up backpack, organizing conferences, chairing scientific sessions and giving lectures at universities.

In this spirit, Fuchs has pioneered a new form of literature. In 2011 Cambridge University Press published his e-mail correspondence with scientists around the world in a 600-page tome entitled *Coming of Age with Quantum Information*. As it chronicles the birth pangs of QBism, it offers a glimpse of how theoretical physics is created by real-life, warm-blooded human beings, not the two-dimensional creatures of Wikipedia. The book also documents Fuchs's conviction, contrary to most scientists, that philosophy matters, not only in the way in which it influences physics but also in the manner in which it is informed by the profound insights of physics—or should be.

POSSIBLE PROBABLES

FUCHS'S OPENNESS to philosophical concerns becomes clear when you consider how QBism forces us to reconsider what is meant by probability. Probability is like "time": we know what it is, until we are asked to define it. Sure, the 50 percent probability of throwing heads with a fair coin implies something about 100 tosses, but how does that intuition help to make sense of the proposition that "the probability of rain this evening is 60 percent," or President Barack Obama's 55/45 assessment, before the event, of the probability of success for the bin Laden operation?

Over the past three centuries two competing definitions of probability have been developed, each with countless variants. The modern, orthodox alternative, called frequentist probability, defines an event's probability as its relative frequency in a

Illustrations by Anna-Kaisa Jormanainen

Four Interpretations of Quantum Mechanics

What is really happening in the quantum world? Scientists have offered about a dozen different interpretations of what the mathematical formalism implies. Quantum Bayesianism is perhaps the most radical; these four alternatives are among the most popular.



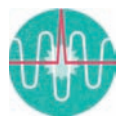
THE COPENHAGEN INTERPRETATION, developed principally by Niels Bohr and Werner Heisenberg at the former's institute in Copenhagen, is the orthodox version of quantum mechanics. The measurable properties of a system such as an atom are collectively called its quantum state. The quantum state, in turn, is described either by a matrix, which resembles a spreadsheet, or a formula called the wave function, which represents a map of possibilities. Contact with the real world is made by the Born rule, a recipe for obtaining measurable probabilities for a given quantum state (and for which Heisenberg's mentor Max Born received a Nobel Prize). During a measurement an observer causes a collapse of the quantum state into a new state that describes the actual outcome of the experiment. The instantaneous collapse implies that actions can have effects that travel faster than light.



THE GUIDING FIELD INTERPRETATION. A number of physicists, including Albert Einstein for a while, favored rewriting the mathematical apparatus of quantum mechanics to include a real physical field of force that controls the motion of a particle. Unfortunately, this appealing image breaks down as soon as several particles, say *N* of them, are involved. They do not move in our familiar three-dimensional space but in an abstract space with 3*N* dimensions. More troubling is the fact that the guiding field exerts an action-at-a-distance force, in which physical effects are transmitted instantaneously over large distances.



THE MANY-WORLDS INTERPRETATION. The most direct way of avoiding the conundrum of quantum state collapse is to eliminate it. This drastic move has gathered many supporters in recent years. The many-worlds interpretation posits a single quantum state of the world, which unfolds smoothly and predictably. When an experiment is performed to ascertain which of two slits an electron traversed, for example, the quantum state does not collapse onto one slit. Instead the world actually splits into two branches. We, the observers of the real world, reside on one branch and are unaware of the other. Thus, the universe really branches out like a tree into a vast multiverse in which every possible outcome actually occurs in one of an infinity of distinct, real universes. The principal drawbacks of this interpretation, aside from its exorbitant demands on our imagination, are its failure to account for the "measurements" that lead to branching and its difficulty in justifying the Born rule.



SPONTANEOUS COLLAPSE THEORIES. Rather than eliminating the observer-triggered collapse, these theories posit that collapses are entirely natural—they happen spontaneously, though rarely, to every quantum system but become significant when the quantum system interacts with a macroscopic object. Yet they require the invention of an entirely new mechanism of collapse. As long as the collapse mechanism cannot be tested experimentally, it constitutes a new assumption that is every bit as mysterious as the observer-induced collapse it is designed to replace.

series of trials. This number is claimed to be objective and verifiable, as well as directly applicable to scientific experiments. The typical example is the coin toss: In a large number of throws, about half will be heads, so the probability for finding heads is approximately ½. (To avoid the vague words "large," "about" and "approximately," the definition is refined to require an infinite number of tosses, in which case the probability takes on its exact value of ½. Unfortunately, the value also becomes unverifiable at this point and thereby loses its claim to objectivity.) Applying this definition to weather prediction, one might count real or simulated weather patterns, but as far as President's Obama's hunch is concerned, the frequency interpretation is useless—the bin Laden mission was manifestly irreproducible.

The older point of view, Bayesian probability, is named after 18th-century English clergyman Thomas Bayes, whose ideas were perfected and promulgated by French physicist Pierre-Simon Laplace. In contrast to frequentist probability, Bayesian probability is subjective, a measurement of the *degree of belief* that an event will occur. It is a numerical measure of how an agent would bet on the outcome of the event. In simple cases such as coin tosses, frequentist and Bayesian probabilities agree. For the prediction of the weather or of the outcome of a military action, the Bayesian, unlike the frequentist, is at liberty to combine quantitative statistical information with intuitive estimates based on previous experience.

The Bayesian interpretation easily deals with single cases, about which frequentism is silent, and avoids the pitfalls of infinity, but its real power is more specific. On the basis of this interpretation, probability assignments are subject to change because degrees of belief are not fixed. A weather forecaster who is a frequentist would have no trouble calculating the likelihood of rain if the region has had a stable, predictable climate for many years. But in the case of a sudden change, such as a drought, for which there are little data, a Bayesian forecaster is better equipped to account for the new information and the climate condition.

Central to the theory is an explicit formula, called Bayes' law, for calculating the effect of new information on the estimate of a probability. For example, when a patient is suspected of having cancer, the physician assigns an initial probability, called the prior, based on data such as the known incidence of the disease in the general population, the patient's family history, and other relevant factors. On receiving the patient's test results, the doctor then updates this probability using Bayes' law. The resulting number is no more and no less than the doctor's personal degree of belief.

Most physicists profess faith in frequentist rather than Bayesian probability, simply because they have been taught to shun subjectivity. But when it comes to making a prediction, the Bayesian approach rules, says Marcus Appleby, a mathematician at the University of London, who credits Fuchs with convincing him of the significance of Bayesian probability.

Appleby points out that we would consider it crazy to bet in a lottery after learning that the same person has won it every week for 10 years, even though a strict frequentist would argue that the results of prior draws have no effect on future outcomes. In practice, no one would ignore the outcome of the previous weeks. Instead the commonsense move would be to adopt the Bayesian viewpoint, update our knowledge and act according to the best available evidence.

Asserting that Schrödinger's cat is truly both alive and dead is an absurdity, ***a megalomaniac's delusion that one's personal state of mind makes the world come into being.***

REWRITING QUANTUM RULES

ALTHOUGH QBISM NEGATES the reality of the wave function, it is not some nihilistic theory that negates all reality, emphasizes QBism co-author Schack. The quantum system examined by an observer is indeed very real, he notes. Philosophically, Mermin says, QBism suggests a split or boundary between the world in which the observer lives and that person's experience of that world, the latter described by a wave function.

Mathematically, Fuchs recently made an important discovery that could help cement QBism's stake as a valid interpretation of probability and quantum theory. The finding has to do with the empirical formula, known as the Born rule, which tells observers how to calculate the probability of a quantum event using the wave function. (In technical terms, the Born rule says that we can measure the likelihood of finding a quantum system with property X by taking the square of the magnitude of the wave function assigned to X.) Fuchs demonstrated that the Born rule could be rewritten almost entirely in terms of the language of probability theory, without referring to a wave function. The Born rule used to be the bridge that connected wave functions to the results of experiments; now Fuchs has shown that we can predict the results of experiments using probabilities alone.

For Fuchs, the new expression of the Born rule provides another hint that the wave function is just a tool that tells observers how to calculate their personal beliefs, or probabilities, about the quantum world around them. "The Born rule in these lights is an addition to Bayesian probability, not in the sense of a supplier of some kind of more-objective probabilities, but in the sense of giving extra rules to guide the agent's behavior when he interacts with the physical world," Fuchs writes.

The simplicity of the new equation is striking. Except for one tiny detail, it resembles the law of total probability, the logical requirement that the probabilities for all possible outcomes add up to unity—for example, for a coin flip, the probability of landing on heads (½) plus the probability of landing on tails (½) must equal 1. The deviant detail—the one and only reference to quantum mechanics in this prescription for how to calculate probabilities in quantum theory—is the appearance of d, the quantum dimension of the system. Dimension in this sense does not refer to length or width but to the number of states a quantum system can occupy. For instance, a single electron that can either have spin up or spin down would have a quantum dimension of 2.

Fuchs points out that quantum dimension is an intrinsic, irreducible attribute that characterizes the "quantum nature" of a system, in the same way that the mass of an object characterizes its gravitational and inertial properties. Although d is implicit in all quantum-mechanical calculations, its explicit, prominent appearance in a fundamental equation is unprecedented. With the Born rule in its new coat, Fuchs hopes to have discovered the key to a new perspective on quantum mechanics. "I toy," he confesses, "with the idea of [the Born rule] being the most significant 'axiom' of all for quantum theory."

A NEW REALITY

ONE OF THE CRITICISMS of QBism is that it is unable to explain complex macroscopic phenomena in terms of more primitive microscopic ones in the way that conventional quantum mechanics does. The most direct way of meeting that challenge is for QBism to succeed in its stated aim of building the standard theory of quantum mechanics on a foundation of new, compelling assumptions.

That goal has yet to be reached, but even now QBism offers a new view of physical reality. By interpreting the wave function as personal degrees of belief, it gives precise, mathematical meaning to Bohr's intuition that "physics concerns what we can say about nature." And proponents of QBism embrace the notion that until an experiment is performed, its outcome simply does not exist.

Before the speed or position of an electron is measured, for example, the electron does not have a speed or a position. The measurement brings the property in question into being. As Fuchs puts it, "With every measurement set by an experimenter's free will, the world is shaped just a little as it participates in a kind of moment of birth." In this way, we become active contributors to the ongoing creation of the universe. SA

MORE TO EXPLORE

Quantum Mechanics: Fixing the Shifty Split. N. David Mermin in *Physics Today*, Vol. 65, No. 7, page 8; July 2012.

Interview with a Quantum Bayesian. Christopher A. Fuchs. http://arxiv.org/abs/1207.2141

QBism, the Perimeter of Quantum Bayesianism. Christopher A. Fuchs. http://arxiv.org/abs/1003.5209

SCIENTIFIC AMERICAN ONLINE

Video: What is a wave function? ScientificAmerican.com/jun2013/wave-function

NEUROSCIENCE

Breaking the Brain Barrier

A new understanding of the blood-brain barrier as a living, mutable organ may revolutionize the treatment of diseases such as cancer and Alzheimer's

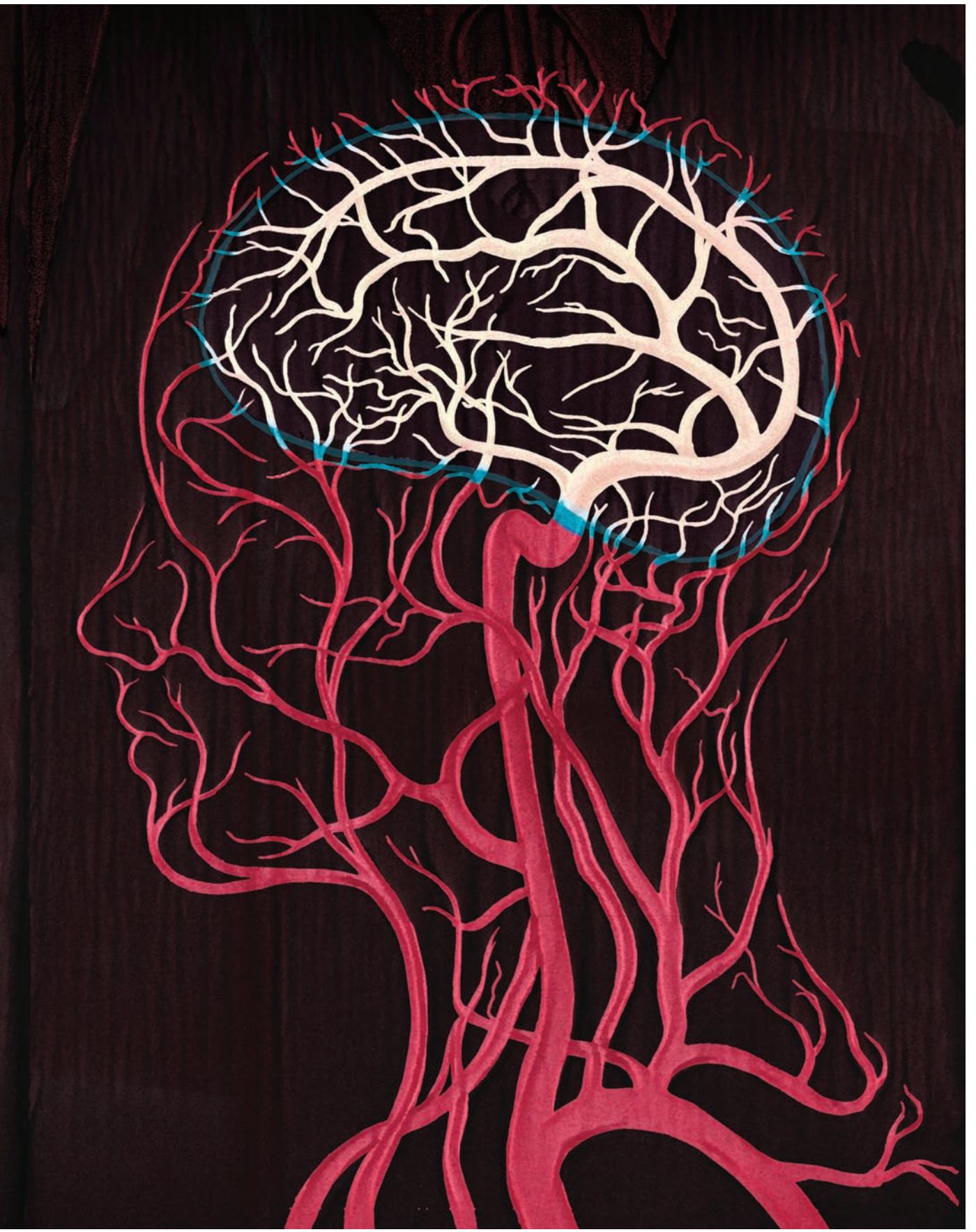
By Jeneen Interlandi

During one of his famous staining experiments of the late 1800s—the kind that would eventually lead to a cure for syphilis and a Nobel Prize for Medicine—Paul Ehrlich stumbled on a conundrum that would haunt medicine down to the present day. When he injected dye into the bloodstream of mice, it penetrated every organ except the brain. Kidneys, livers and hearts turned a dark purplish-blue, clear and stark under his microscope, but the brain remained a pale whitish-yellow. When a student of his injected that same dye directly into the brain, the opposite happened: the brain itself turned blue, whereas the other organs did not. Clearly, the student thought, a barrier—in German, *Blut-Hirn-Schranke*—must exist between brain and blood.

It would take half a century and a microscope roughly 5,000 times more powerful than Ehrlich's for anyone to actually locate this barrier, hidden as it was inside the brain's blood vessels. The average human brain houses roughly 400 miles of such vessels. They bend and twist in an endless array of tangled loops, ultimately ensnaring every single one of the human brain's 100 billion or so neurons. The walls of all these vessels are lined with endothelial cells. To be sure, endothelial cells line the interior of all of the body's vasculature, but they are much more tightly packed in the brain's vessels than they are anywhere else in the body, which explains why neither Ehrlich's dyes nor most of the medications in existence could cross from the bloodstream into the brain.

But long before they could visualize the barrier, doctors had come to both revere and avoid it. "For ages we saw it as like a

Illustration by Alex Nabaum



brick wall," says Lester Drewes, a vascular biologist and blood-brain barrier specialist at the University of Minnesota. "And the consensus was that it's there for a reason, and we shouldn't mess with it."

That consensus has shifted. As scientists now know, that brick wall is actually thrumming with activity. Cells on both sides—blood and brain—are constantly communicating with and influencing one another. Not only that, but a wide array of molecular passageways embedded in the endothelial membrane regulate traffic, blocking some substances while shepherding others across. Even white blood cells, long thought to be too large to penetrate the barrier, slip across regularly to patrol for invaders.

Scientists have adopted the term "neurovascular unit" to better describe what they see: not just a wall made up of endothelial cells but a vital organ of sorts, one that consists of many different cell types, including those surrounding the vessels, and plays its own crucial role in development, aging and illness. Thanks to another revolution in microscopy, they are seeing this organ more closely and clearly than ever before.

Jeneen Interlandi is a freelance science journalist based in New York City. She has spent the past year as a Nieman Fellow at Harvard University studying the history of science and medicine.



BROKEN BARRIERS

AT THE UNIVERSITY of Rochester, the view through Maiken Nedergaard's "two photon" microscope is infinitely more dazzling than even Ehrlich could have imagined. Of course, unlike him, she is looking at a brain that is still inside a living, breathing animal (a mouse, to be precise). She has removed a bit of the creature's skull and injected dye into its circulation, and now she is watching the blood-brain barrier in real-time: individual cells are crossing out of the bloodstream across capillary walls, which consist of a single layer of endothelial cells. The march is stunning to behold, especially given how inaccessible the barrier was when Nedergaard started her career, some 20 years ago.

Before the advent of two-photon microscopy—an advanced form of imaging that can penetrate the top 300 microns of cortex—researchers could not do much better than Ehrlich; they studied dead tissue fixed to traditional microscope slides. Those kinds of experiments, Nedergaard says, told biologists very little about how the blood-brain barrier actually operates. That is because blood flow is essential to the proper functioning of both brain and barrier—just how essential has surprised and excited scientists who study the barrier.

For example, in a string of recent experiments Nedergaard and her colleagues have shown that when a given cluster of neurons is stimulated, the surrounding blood vessels increase in diameter, thus delivering more blood and nutrients to those neurons at the exact moment that the neurons start firing. If you slow down that stimulation, the vessels contract, and nutrient delivery diminishes. "It's incredibly dynamic," Drewes says.

It is also incredibly complex. The capillaries are looped by astrocytes and pericytes—cells that envelop the entire vascular system and appear to facilitate communication between blood, endothelia and neurons. These cells are in turn orbited by other cells.

Of these, Nedergaard is most intrigued by microglial cells, the central nervous system's resident macrophages, or defensive cells; microglia patrol the brain and spinal cord for damaged cells and infectious agents, which they then devour. Malfunctioning microglia have already been implicated in a wide range of neurodegenerative diseases—from Alzheimer's to Parkinson's—and Nedergaard suspects that their role in those disorders may have something to do with falling down on the job of protecting the blood-brain barrier.

Nedergaard reasons that every time endothelial cells die, as they do both naturally and in response to injury, their loss must leave a transient opening in the barrier, one that surviving endothelial cells would be too slow to close, given that they are sewn together by links known as tight junctions. The presence of these linkages would mean that in healthy brains, some other cell type must act to close those gaps. In one set of experiments, Nedergaard wielded a laser to breach brain capillaries in live mice. Within 10 to 20 minutes, she says, microglial cells had completely surrounded the damaged area. "They ensheathed the capillary with amazing speed," she says. "It was actually quite beautiful."

Her team is now trying to find out if microglial cells are in fact the first line of defense—the emergency crew that comes out and temporarily closes the barrier until damaged endothelial cells can be repaired or replaced. "You could imagine," Nedergaard says, "that if the microglial cells are not functioning properly, then small leaks aren't repaired as fast, and you get neurodegeneration." Her hypothesis is just one of many that scientists are testing as they work to understand what role the blood-brain barrier plays in disease.

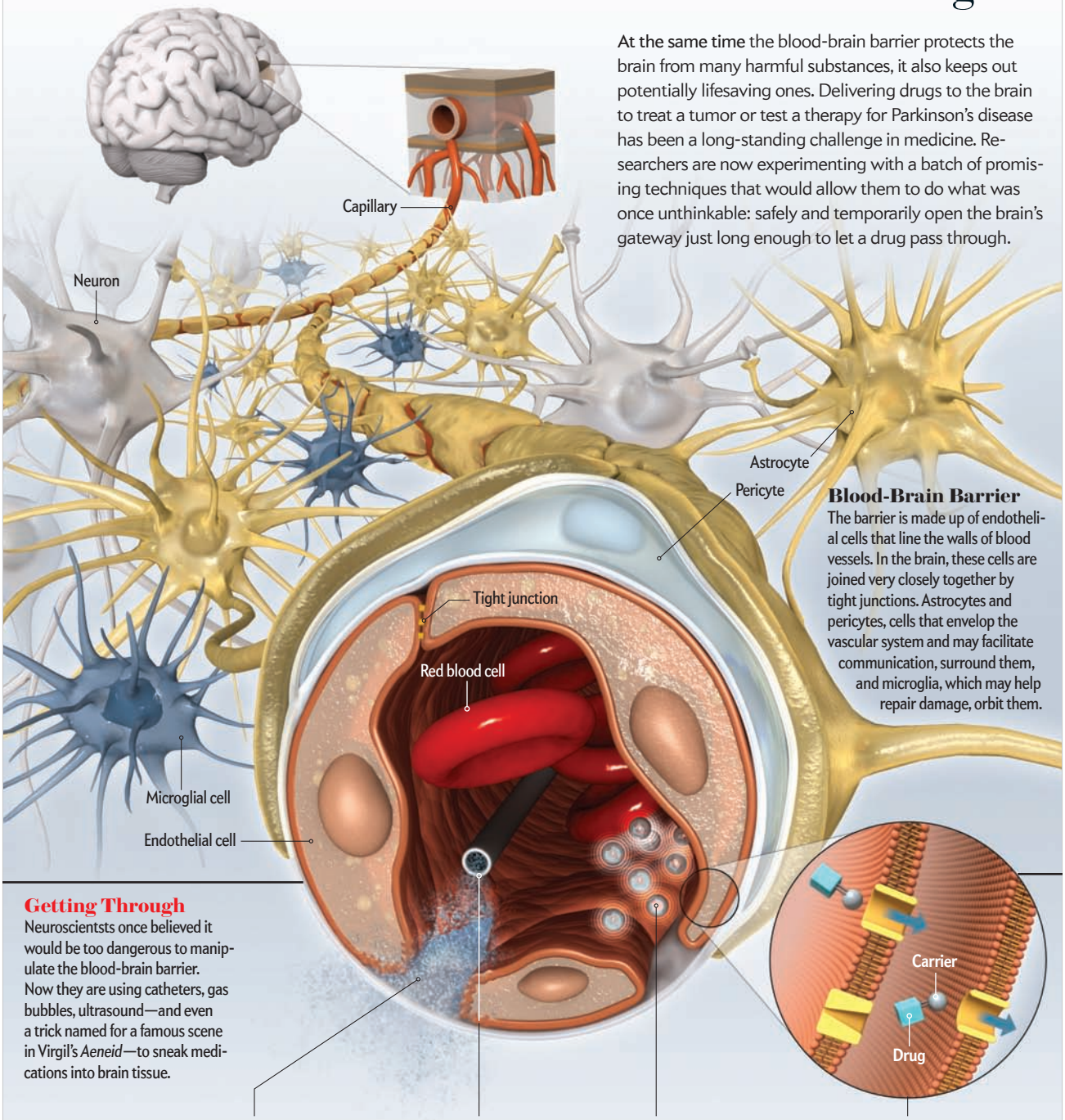
Take, for example, multiple sclerosis, a disorder that is characterized by episodes of debilitating muscle pain, numbness and vision trouble. Doctors have known for ages that MS is caused by the breakdown of myelin, a rubbery sheath that

IN BRIEF

For more than a century, scientists believed that the blood-brain barrier was a sacred, impermeable wall. In fact, it is made up of ordinary blood vessels with one extraordinary property: the cells that make up their lining are packed together so tightly that they allow very few substances to cross into brain tissue.
The barrier is a vital organ in its own right, thrumming with activity as cells communicate with one another to decide which molecules to block and which ones to let through. Many more cells pass through the barrier than scientists previously realized.
To reflect this new understanding, scientists now call the blood-brain barrier the neurovascular unit.
Many believe that learning how to open and close it may be the key to curing a host of diseases.

Border Crossings

At the same time the blood-brain barrier protects the brain from many harmful substances, it also keeps out potentially lifesaving ones. Delivering drugs to the brain to treat a tumor or test a therapy for Parkinson's disease has been a long-standing challenge in medicine. Researchers are now experimenting with a batch of promising techniques that would allow them to do what was once unthinkable: safely and temporarily open the brain's gateway just long enough to let a drug pass through.



Blood-Brain Barrier

The barrier is made up of endothelial cells that line the walls of blood vessels. In the brain, these cells are joined very closely together by tight junctions. Astrocytes and pericytes, cells that envelop the vascular system and may facilitate communication, surround them, and microglia, which may help repair damage, orbit them.

Getting Through

Neuroscientsts once believed it would be too dangerous to manipulate the blood-brain barrier. Now they are using catheters, gas bubbles, ultrasound—and even a trick named for a famous scene in Virgil's *Aeneid*—to sneak medications into brain tissue.

HYPEROSMOTIC SOLUTION

Some solutions, like mannitol, have the capacity to suck moisture out of surrounding tissues. When doctors inject mannitol into an artery leading to the brain, it absorbs water from the brain's endothelial cells, causing them to shrivel up. The tight junctions then open, and drugs can slip through.

MICROCATHETERIZATION

Doctors thread a tiny catheter through the blood vessels up to the brain and use mannitol to open a small part of the barrier near the site they wish to treat. Next they inject drugs via the same catheter. This method is already used to administer anticlotting agents following a stroke.

MICROBUBBLES

Club soda in the bloodstream? A physician injects the patient with a saline solution containing microscopic gas bubbles. Once they reach the brain, a beam of focused ultrasound makes them vibrate in a specific location, causing the blood-brain barrier to open and allow drugs to pass through.

TROJAN HORSES

The name suggests a drug hidden inside something else, but these drugs actually come attached, like a wagon, to the end of a compound that slips naturally across the blood-brain barrier. Drug company Genentech has shown that these work in mice, but human trials are several years away.

Illustration by Emily Cooper

encases and insulates the axons (the signal-emitting "wires") of neurons just as rubber encases telephone wire. But why these attacks occur in episodes and what triggers those episodes have remained a bit of mystery. A growing roster of magnetic resonance imaging studies suggests that breaches in the blood-brain barrier precipitate MS attacks. These aberrant openings allow too many white blood cells to cross from the capillaries into the brain and attack the myelin. Based on a few new studies, scientists now think that highly reactive oxygen molecules may attack and thereby weaken the barrier, essentially rusting it, and that antioxidants, which block the effects of the reactive molecules, may thus make for good barrier stabilizers. "We have always thought of MS as a disease of the immune system," Drewes remarks. "Now we're starting to think of it as a disease of the blood-brain barrier."

The same seems to go for epilepsy. Doctors and scientists have known for some time that seizures correspond to transient disruptions of the blood-brain barrier, but until recently most have assumed that those breaches are a consequence of the seizures, not a cause. That thinking has begun to change. Epilepsy researchers at the University of Amsterdam have found that artificially disrupting the blood-brain barrier of rats is a reliable way to increase the number of seizures they suffer and that the more a rat's barrier has been disrupted, the more likely the animal will develop temporal lobe epilepsy. Studies conducted at the Cleveland Clinic in both pigs (experimental) and humans (observational) also found that seizures occurred after—not before—the barrier was disrupted.

Scientists elsewhere have identified two barrier proteins whose malfunctioning might play a role in Alzheimer's disease. One protein (known as RAGE) shepherds the molecule beta-amyloid into the brain from the bloodstream; the other (called LRP1) shoos it out. When the balance between these two is disturbed—when too much beta-amyloid is let in or too little is expelled—the brain plaques associated with Alzheimer's arise. Although clinical applications are a long way off, the finding has given at least some cause for hope: in mouse experiments, researchers were able to prevent the buildup of beta-amyloid by blocking the functioning of the gene that gives rise to the RAGE protein in endothelial cells; it is at least possible that RAGE-inhibiting drugs (which are now being developed) might accomplish the same feat in humans.

Of course, repairing leaks in the barrier is only half the challenge. The other half is creating deliberate openings so that needed drugs can get across. So far doctors have found at least one proven way to do this, and the race is on to find as many more as possible.

Of course, repairing leaks in the barrier is only half the challenge. The other half is creating openings so that needed drugs can get across.

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OPEN SESAME

FOR ALL ITS COMPLEXITY, traffic between the bloodstream and brain is governed by an exceedingly simple set of rules. To cross, a compound must either be smaller than 500 kilodaltons (like most antidepressants, antipsychotics and sleep aids), able to use one of the natural gateways embedded in the barrier itself (like the Parkinson's drug L-dopa), or be lipophilic, meaning it has an affinity for lipids and can thus bind to and slip across the lipid cell membrane (like alcohol, cocaine and heroin). By most estimates, 98 percent of all medications fail to meet any of these criteria, which means they cross the barrier in quantities so minuscule as to be medically useless—or they do not cross at all.

Past efforts to exploit these rules have been fraught. Making drugs more lipid-soluble, for example, enabled them to penetrate the blood-brain barrier with relative ease, but as scientists soon discovered, this strategy had several downsides. Some drugs crossed over, only to be kicked out rather quickly; others got stuck in the membrane itself and so could not do their jobs. Meanwhile all of them penetrated the body's other organs with an alarming lack of discrimination.

As a medical resident some 30 years ago, Edward A. Neuwelt lit out on a different path. A neurosurgeon and director of Oregon Health and Science University's Blood Brain Barrier Program, Neuwelt developed the first surgical procedure for breaching the barrier. First, he injects a solution called mannitol into an artery leading to the brain. Because mannitol is hyperosmotic, meaning that it contains significantly more solute than the brain's endothelial cells do, the solution sucks the water out of the cells, causing them to shrivel up like fingertips soaked in water too long. The shrinking pulls apart the tight junctions, leaving gaps large enough for drugs (delivered through the same artery) to slip through. Somewhere between 40 minutes and two hours later, the endothelial cells will swell back to their normal size, re-forming tight junctions and sealing the barrier once again.

For nearly two decades Neuwelt has been using this technique to pry open the blood-brain barrier of a very specific type of patient: those with brain tumors that might be expected to respond to chemotherapy, if only the drugs could get across.

One of those patients was Joanie Lafferty, a 57-year-old mother of three who, back in 2007, was diagnosed with central nervous system lymphoma (a cancer that starts in the lymphatic

system and spreads to the brain). Doctors gave her roughly one month to live. When she first arrived at O.H.S.U.—two weeks after the initial brain biopsy—the right side of her body was paralyzed. Her insurance company had cautioned her against the procedure, which they said was still experimental and could trigger a stroke or cause permanent epilepsy, or worse. But as far as Lafferty was concerned, she had nothing to lose. "This was the only option on the table," she said. "And I wanted to live."

Thus, just a few weeks after being diagnosed, Lafferty let Neuwelt and his team thread a catheter through her groin, up into her left carotid artery, then use it to deliver two solutions: the hyperosmotic mannitol, followed quickly by the chemotherapeutic methotrexate. The next day they repeated the procedure, using her right carotid artery instead. A month later, and every month after that for a year, Neuwelt and his team repeated the protocol: first through the left artery, then the right, mannitol pried open her blood-brain barrier so that methotrexate could be shot across and attack her tumor. By the end of her second treatment, she was able to walk out of the hospital without a wheelchair. Two months later she was in full remission. Five years later she still is.

For patients younger than 60, Neuwelt's team boasts a median survival of 13 to 14 years, with significantly better cognitive outcomes, compared with standard whole-brain radiation treatment. Of course, not all cancer drugs can be delivered across the barrier, and not all brain tumors can be treated in this way. So far only a handful of drugs have been tested and proved safe for delivery. Because the procedure sends mannitol from the carotid through the entire brain and thus opens much of the barrier, it carries risks of tissue swelling, infection and toxicity.

Even as Neuwelt and his team work to refine their procedure and expand its application, doctors elsewhere are developing alternatives. One of the most promising is direct microcatheterization. Like Neuwelt's barrier-disruption technique, this method also involves threading a catheter into the blood vessels and using mannitol to pry the barrier open. Rather than stopping at the carotid artery, however, the microcatheter reaches all the way up into the brain itself and opens just a tiny portion of the barrier, near the site of pathology. "It's a very targeted procedure," says John Boockvar, who is the New York Presbyterian Weill Cornell neurosurgeon leading the clinical trial.

Whether that will be an advantage or disadvantage remains to be seen. On one hand, opening less of the barrier reduces the risk of tissue swelling and seizures, not to mention the amount of brain tissue that is exposed to toxic chemotherapy. On the other hand, as Neuwelt points out, site specificity is a disadvantage when it comes to treating whole-brain diseases such as cancer or even advanced Alzheimer's. "With microcatheter, you're only attacking the tumor you can see," he says. "But with brain tumors especially, it's the spots you can't see that end up killing you."

Microcatheterization is already routinely used to deliver anticlotting agents to the brain in stroke victims; Boockvar and his team are testing its efficacy in delivering several antitumor drugs. Eventually, they say, the technique could be used to treat Alzheimer's, Parkinson's or, theoretically, any brain disease for which medications exist but need help crossing the barrier.

Another strategy for breaching the barrier involves focused ultrasound and microbubbles (microscopic gas bubbles). Researchers inject saline solution containing microbubbles into the bloodstream. They then apply a focused ultrasound beam, which causes the bubbles to vibrate rapidly, prying open the tight junctions at a precise location. Drugs—also injected into the bloodstream—can then slip into the brain. Some time later the tight junctions re-form, closing the barrier once again. Researchers at Harvard University, Columbia University and other institutions are developing microbubbles and focused ultrasound. The technique has proved safe in monkeys and is progressing rapidly toward human trials.

Of course, breaking the barrier open is not the only way to get drugs across; another way is to sneak them through the barrier's existing portals by attaching them to compounds that use those portals naturally. Scientists working to develop such drugs refer to them as Trojan horses, which is a bit of a misnomer. The drug is not hidden inside the familiar compound but rather is attached to the end, like a wagon. In some cases, however, the method works. A Trojan horse developed by Genentech was able to reduce brain plaques by 47 percent in rodent experiments. This particular drug enters the brain through the same receptors that transport iron across the barrier. Similar drugs (for not only Alzheimer's but other neurodegenerative diseases) are being developed at the University of California, Los Angeles, and elsewhere, each progressing slowly toward the same goal: drugs ready for human trials.

ALPHA AND OMEGA

IN THE MEANTIME, evidence of the barrier's significance is quickly seeping past the study of diseases into the fundamental processes of development and aging—the beginning and end of life itself. Experiments in the 1920s suggested that the barrier was immature in newborns, a perception that persists among developmental biologists and barrier researchers today. But recent studies have shown that tight junctions form almost as soon as blood vessels begin to penetrate the embryonic brain. In fact, investigators have begun to suspect that the barrier plays a crucial role during development by providing the brain with a specialized internal environment without which neurons might not be able to grow and connect.

Then, as we grow old, that specialized environment may start to come apart. Researchers have begun to suspect that subtle changes in the blood-brain barrier—a reordering of cerebral vasculature, perhaps, or small, slow leaks in the barrier itself—are what clear the path for age-related neurodegeneration, in all its malevolent permutations. "It's the next big thing we have to look into," says Drewes, who has been studying the barrier for well over two decades. "It seems our biggest lesson yet might be how very little we actually understand."

MORE TO EXPLORE

Development of the Blood-Brain Barrier: A Historical Point of View. Domenico Ribatti, Beatrice Nico, Enrico Crivellato and Marco Artico in *Anatomical Record,* Part B: *New Anatomy,* Vol. 289, No. 1, pages 3–8; 2006.

Engaging Neuroscience to Advance Translational Research in Brain Barrier Biology. Edward A. Neuwelt et al. in *Nature Reviews Neuroscience,* Vol. 12, No. 3, pages 169–182; March 2011.

Ultrasound Elasticity Imaging Laboratory at Columbia University. **http://orion.bme.columbia.edu/ueil/research.php**

SCIENTIFIC AMERICAN ONLINE

View the blood-brain barrier as seen through a microscope at ScientificAmerican.com/jun2013/bbb



HOBOKEN, N.J.: Sandy's storm surge flooded downtown and cut off power.



STATEN ISLAND: At least 17 residents drowned despite protective levees.



MANHATTAN: Superstorm Sandy engulfed streets and filled subway tunnels.

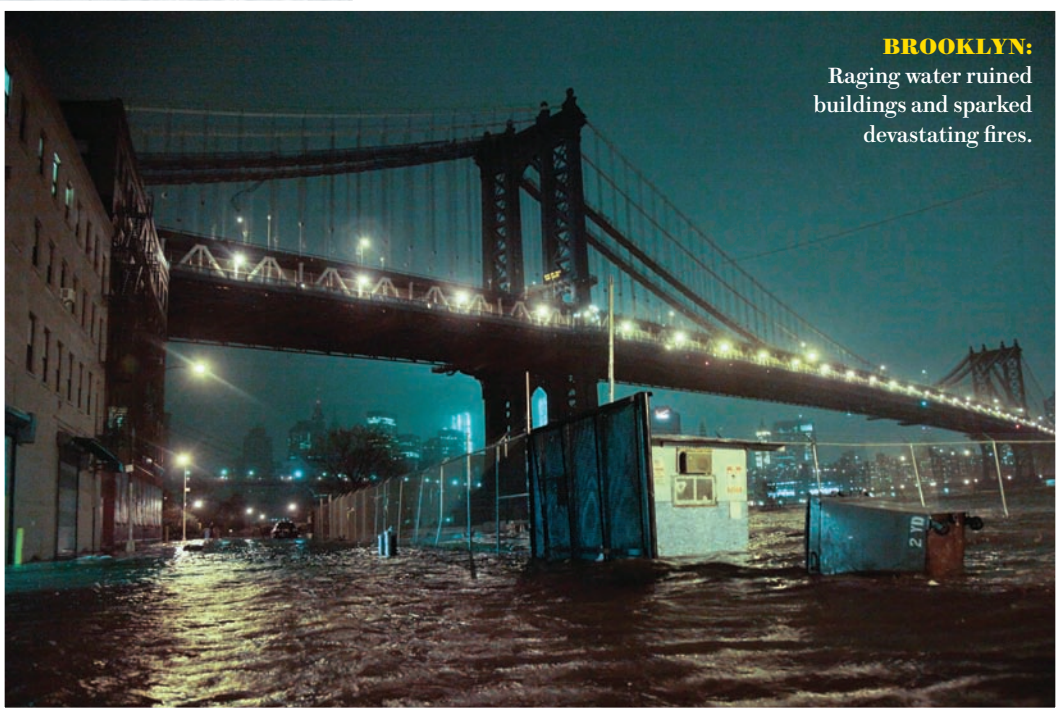
CLIMATE SCIENCE

STORM OF THE CENTURY*

*EVERY TWO YEARS

New York City and the entire U.S. East Coast could face frequent destruction unless the region takes drastic action

By Mark Fischetti *Maps by XNR Productions*



BROOKLYN: Raging water ruined buildings and sparked devastating fires.

THOMAS ABDALLAH HAS SEEN A LOT OF WATER in his 26 years of work for New York City's transit system. In December 1992 a nor'easter storm killed the subway's power, forcing rescue crews to evacuate passengers from flooding tunnels. In August 2007 a five-inch deluge that meteorologists called an "extreme climate event" shut down the system again. So did Hurricane Irene in August 2011. Then came Hurricane Sandy.

As Sandy's storm surge began to flood downtown Manhattan last October, dozens of New York City transit workers scrambled in the wind and rain to place plywood sheets and sandbags across subway entrances. But the oncoming water pushed right through the feeble barricades, pouring down stairwells until underground stations filled chest deep, in turn filling seven long train tunnels running under the rivers between the boroughs. Huge pumps in more than 300 man-made caverns deep below the city's subway line, which can push out 18 million gallons of water a day, couldn't possibly keep up.

After the deluge, Abdallah, who is the transit system's chief environmental engineer, assessed the damage with his colleagues. Saltwater had corroded electrical equipment throughout the subway system. Much of it had to be replaced. The transit authority chair at the time, Joe Lhota (now running for mayor), testified before Congress that fully restoring the system would cost $5 billion. And that would just bring the subways back to their pre-Sandy condition; the money would do nothing to enhance protection against the next hurricane or against rising seas.

That status quo is becoming increasingly costly in money and lives. Experts predict that damaging storms will get more severe and more frequent. According to the latest estimates, the chance of widely destructive flooding in New York City will be one in two each year by the end of the century unless significant infrastruc-

IN BRIEF

The chances of severe flooding in New York City will be as high as one in two each year by 2100, in part because the U.S. East Coast is a hotspot for sea-level rise.

Experts may be reluctant to recommend the ultimate protection measures for New York City: building massive barriers that would cost billions of dollars and moving communities out of the lowest-lying areas.

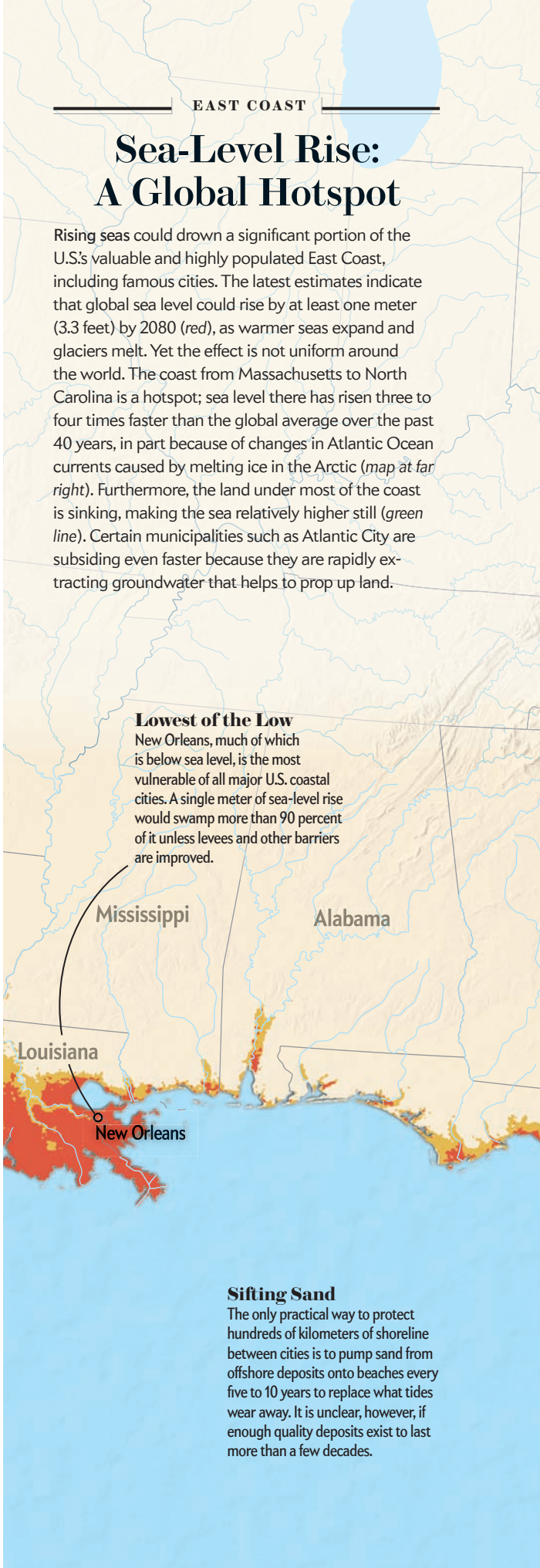
The primary way to protect long coastlines between cities is to pile sand along beaches every five to 10 years, but it is unclear whether enough quality sand deposits exist offshore.

Ending federal subsidies for flood insurance, so that beachfront residents must pay the full cost, might encourage people to move out of vulnerable areas.

EAST COAST

Sea-Level Rise: A Global Hotspot

Rising seas could drown a significant portion of the U.S.'s valuable and highly populated East Coast, including famous cities. The latest estimates indicate that global sea level could rise by at least one meter (3.3 feet) by 2080 (*red*), as warmer seas expand and glaciers melt. Yet the effect is not uniform around the world. The coast from Massachusetts to North Carolina is a hotspot; sea level there has risen three to four times faster than the global average over the past 40 years, in part because of changes in Atlantic Ocean currents caused by melting ice in the Arctic (*map at far right*). Furthermore, the land under most of the coast is sinking, making the sea relatively higher still (*green line*). Certain municipalities such as Atlantic City are subsiding even faster because they are rapidly extracting groundwater that helps to prop up land.



Lowest of the Low
New Orleans, much of which is below sea level, is the most vulnerable of all major U.S. coastal cities. A single meter of sea-level rise would swamp more than 90 percent of it unless levees and other barriers are improved.

Sifting Sand
The only practical way to protect hundreds of kilometers of shoreline between cities is to pump sand from offshore deposits onto beaches every five to 10 years to replace what tides wear away. It is unclear, however, if enough quality deposits exist to last more than a few decades.

PRECEDING PAGES: COURTESY OF NASA VISIBLE EARTH (*satellite image*); GETTY IMAGES (*man in water, Hoboken*); CHRISTOS PATHIAKIS *Getty Images* (*cars in flooded street*); BEBETO MATTHEWS *AP Photo* (*Manhattan Bridge*); VICTOR J. BLUE *Getty Images* (*raft*)



SOURCES: "IMPLICATIONS OF RECENT SEA LEVEL RISE SCIENCE FOR LOW-ELEVATION AREAS IN COASTAL CITIES OF THE CONTERMINOUS U.S.A.," BY JEREMY L. WEISS, JONATHAN T. OVERPECK AND BEN STRAUSS, IN *CLIMATIC CHANGE*, VOL. 105, NOS. 3–4; APRIL 2011 (*1-meter and 6-meter sea-level rise data*); "HOTSPOT OF ACCELERATED SEA-LEVEL RISE ON THE ATLANTIC COAST OF NORTH AMERICA," BY ASHBURY H. SALLENGER, JR., KARA S. DORAN AND PETER A. HOWD, IN *NATURE CLIMATE CHANGE*, VOL. 2; 2012 (*sea-level rise gauge data, USGS*)

ture changes are made. Each decade from now until then, the "average" flood will become worse and worse. Billions of dollars in repairs will become commonplace.

New York City is not alone in facing a watery future. The U.S. East Coast—one of the wealthiest and most densely populated regions in the world—is a hotspot for sea-level rise. Melting Arctic ice is changing Atlantic Ocean currents in a way that raises water along the coast. At the same time, the land is subsiding. In 2012 Asbury Sallenger of the U.S. Geological Survey reported that for the prior 60 years, sea level from Cape Cod outside Boston to Cape Hatteras in North Carolina had risen three to four times faster than the global average. Using the data, Sallenger (who died in February) confirmed models by colleagues indicating that by 2100 the mid-Atlantic region would experience 4.7 to 9.4 inches of sea-level rise above and beyond the average global increase, which itself is expected to be several feet at least.

Sandy's damage has focused the minds of scientists, politicians and the public on the vulnerability of coastal areas to storm surges and sea-level rise. Experts are debating which actions could best protect the Eastern seaboard, especially as millions more people flock there. Turning the entire coastline into a fortress is prohibitively expensive and would ultimately be a losing proposition for many sandy coastlines. Yet the alternative—moving people away from the water—would be a political tinderbox and cause social and economic disruption.

This dilemma is being played out in New York City, where scientists and engineers are scrambling to present protection options to Mayor Michael R. Bloomberg by the end of May. They were expected to recommend steps to repel minor flooding, but it is not clear that they would be willing to recommend the only sure way to protect against an 11-foot surge like Sandy's: massive flood barriers that would cost $10 billion to $20 billion. It is also unclear whether they would recommend an end to federal subsidies for flood insurance and the evacuation of low-lying land, even though these steps are the ultimate long-term solutions to the sea-level rise that the latest climate science predicts.

The choices are even more stark for the long stretches of coastlines between cities—along New Jersey, Maryland, the Carolinas, Florida. The U.S. would have to build a wall 16 feet high—to handle storm surge on top of sea-level rise—along every inch of the East Coast. Even if the money for such work were found, the millions of people who live in beachside communities would never stand for it because it would block their ocean view and access. The only politically viable option is to continually pile sand along beaches, even though higher and higher seas will erode more and more of it away—a Sisyphean postponing of the inevitable retreat from the shore.

In interviews with dozens of experts, it is clear that extreme measures needed to harden the East Coast would take decades to complete, cost hundreds of billions of dollars and disrupt many lives, but they are necessary evils.

DEFENDING NEW YORK CITY

SINCE HURRICANE SANDY struck, all eyes have turned toward New York City to see how best to defend against rising water. The metropolis ranks in the top 10 port cities most exposed to flooding worldwide and has more than $2 trillion of coastal property at risk—first or second on the planet. When Cynthia Rosenzweig, a climate scientist at Columbia University, attended a global

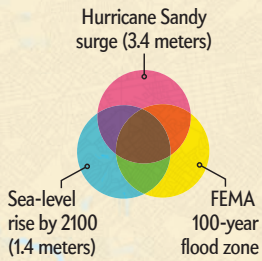
NEW YORK CITY

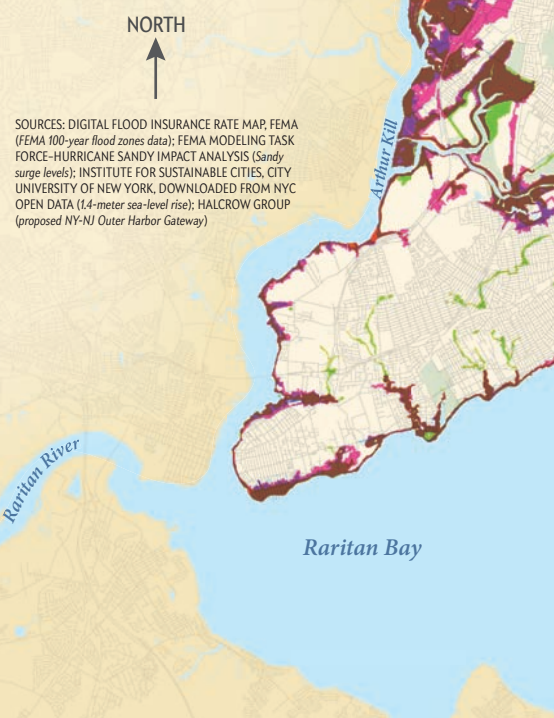
Storm Surge: Block It or Abandon Shore

Storm surge and sea-level rise threaten New York City. Hurricane Sandy's 3.4-meter (11-foot) surge was the highest to hit the city's metropolitan area. Like most cities, New York bases protection plans on maps from the Federal Emergency Management Agency, which show where flooding most likely will occur if a one-in-100-year storm hits. FEMA updated New York's flood zones in January, but Sandy's surge flowed farther inland in many areas (*key below*). Two massive barriers could hold back surges, but residents might have to abandon the lowest-lying communities, which already flood regularly, as seas relentlessly rise.

Flood Levels

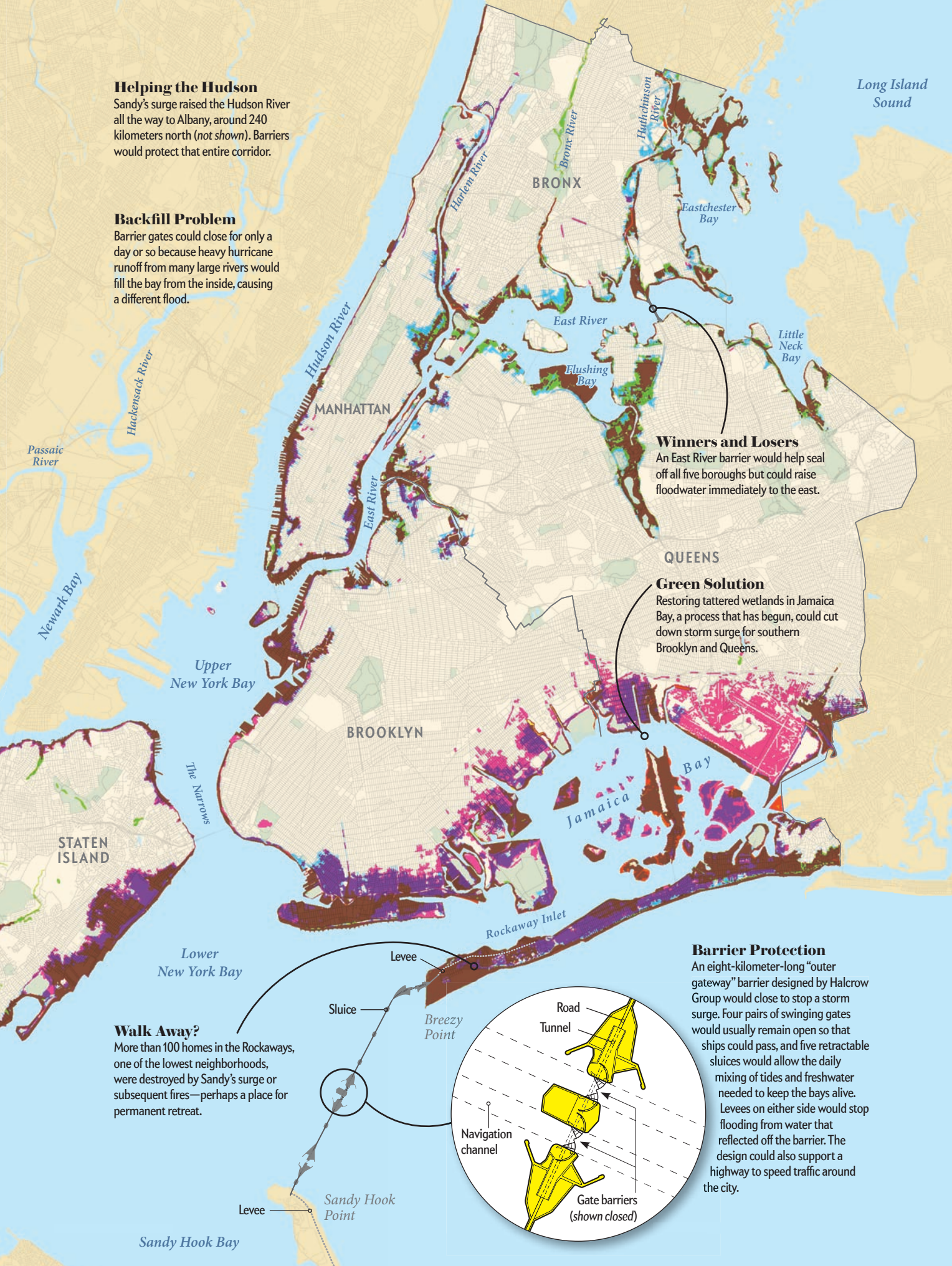
A sea-level rise of 1.4 meters (4.5 feet), projected for 2100, would fall within some of the FEMA flood zones (*green* and *brown*) but would overrun them in other places (*blue* and *purple*). Sandy's storm surge covered all the FEMA area (*brown* and *red*) and much of the 1.4-meter area (*brown* and *purple*) but also moved farther inland than both boundaries in many places (*pink*).





SOURCES: DIGITAL FLOOD INSURANCE RATE MAP, FEMA (*FEMA 100-year flood zones data*); FEMA MODELING TASK FORCE–HURRICANE SANDY IMPACT ANALYSIS (*Sandy surge levels*); INSTITUTE FOR SUSTAINABLE CITIES, CITY UNIVERSITY OF NEW YORK, DOWNLOADED FROM NYC OPEN DATA (*1.4-meter sea-level rise*); HALCROW GROUP (*proposed NY-NJ Outer Harbor Gateway*)

Illustration by George Retseck (inset)


Helping the Hudson
Sandy's surge raised the Hudson River all the way to Albany, around 240 kilometers north (*not shown*). Barriers would protect that entire corridor.
Backfill Problem
Barrier gates could close for only a day or so because heavy hurricane runoff from many large rivers would fill the bay from the inside, causing a different flood.
Long Island Sound
Harlem River
Bronx River
Hutchinson River
BRONX
Eastchester Bay
Hudson River
East River
Little Neck Bay
Flushing Bay
MANHATTAN
Hackensack River
Passaic River
Winners and Losers
An East River barrier would help seal off all five boroughs but could raise floodwater immediately to the east.
East River
QUEENS
Green Solution
Restoring tattered wetlands in Jamaica Bay, a process that has begun, could cut down storm surge for southern Brooklyn and Queens.
Newark Bay
Upper New York Bay
BROOKLYN
Jamaica Bay
The Narrows
STATEN ISLAND
Rockaway Inlet
Lower New York Bay
Levee
Sluice
Breezy Point
Walk Away?
More than 100 homes in the Rockaways, one of the lowest neighborhoods, were destroyed by Sandy's surge or subsequent fires—perhaps a place for permanent retreat.
Road
Tunnel
Navigation channel
Gate barriers (*shown closed*)
Levee
Sandy Hook Point
Sandy Hook Bay
Barrier Protection
An eight-kilometer-long "outer gateway" barrier designed by Halcrow Group would close to stop a storm surge. Four pairs of swinging gates would usually remain open so that ships could pass, and five retractable sluices would allow the daily mixing of tides and freshwater needed to keep the bays alive. Levees on either side would stop flooding from water that reflected off the barrier. The design could also support a highway to speed traffic around the city.

environment meeting after Sandy occurred, city officials from around the world told her they were looking to New York to lead.

Scientists and engineers are scrambling because Sandy and new science have washed out the basic assumptions that the city had made. In 2009 a report by the New York City Panel on Climate Change (NPCC) stated that the city should plan for at least two feet of sea-level rise by 2100, based on conventional climate models. But in 2012 new information from various global sources showed that Antarctica and Greenland are melting quicker than models predicted. According to what scientists call the rapid ice-melt scenario, global sea level will rise four feet by the 2080s, notes Klaus Jacob, a research scientist at Columbia's Lamont-Doherty Earth Observatory. In New York City, by 2100 "it will be five feet, plus or minus one foot," Jacob says flatly.

The NPCC report also did not focus much on storm surges. Sandy's surge topped out at about 11 feet above average sea level at the lower tip of Manhattan. But here's the rub: Flood maps just updated in January by the Federal Emergency Management Agency indicate that an eight-foot surge would cause widespread, destructive flooding. So if sea level rises by five feet by 2100, a surge of only three feet is needed to inflict considerable damage.

Of course, rapid climate change would push the sea higher every decade until then. Jacob says the chance of what had been a one-in-100-year storm surge occurring in New York City will be one in 50 during any year in the 2020s, one in 15 during the 2050s and one in two by the 2080s. Scientists at the Massachusetts Institute of Technology say the chance of a one-in-100-year storm will be as great as one in three by 2100.

Despite the dire odds, none of the more than 20 scientists, engineers and city officials interviewed for this article would articulate a grand plan for protecting New York City against five feet of sea-level rise, plus an 11-foot surge, because that would require politically difficult choices. The lone exception is Jeroen Aerts, who served as an adviser to New York City's Office of Long-Term Planning and Sustainability and Department of City Planning, until they parted ways after Hurricane Sandy.

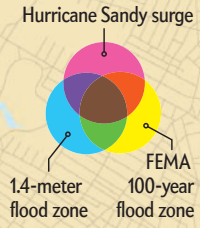
To Aerts, the necessary plan is straightforward. Immediately start flood-proofing buildings, which would harden them against events like the five-inch deluge in 2007. Begin to retrofit subway, train and automobile tunnels so water cannot get in. Armor power plants, wastewater treatment facilities and other "critical infrastructure." Meanwhile start the process of changing zoning laws to discourage construction in the lowest-lying areas. Add seawalls along the low edges of the city's boroughs to fend off rising sea level. And start doing environmental and cost-benefit studies for enormous barriers that would be dropped into the bay to hold back surges. Those studies take years, and construction would take years more, "so it will be 2030 before barriers would be in place," Aerts explains. "In the meantime, you start implementing the 'no regret' steps," such as raising subway entrances so floodwater cannot pour down the stairways onto the tracks.

Aerts was hoping New York would impose a regional plan such as the one he was developing, but in the aftermath of Sandy the groups he was advising told him that regional politics would make a centrally executed plan impossible. That is a far cry from how things work where Aerts comes from: he is a specialist in geographical risk management at the Institute for Environmental

LOWER MANHATTAN

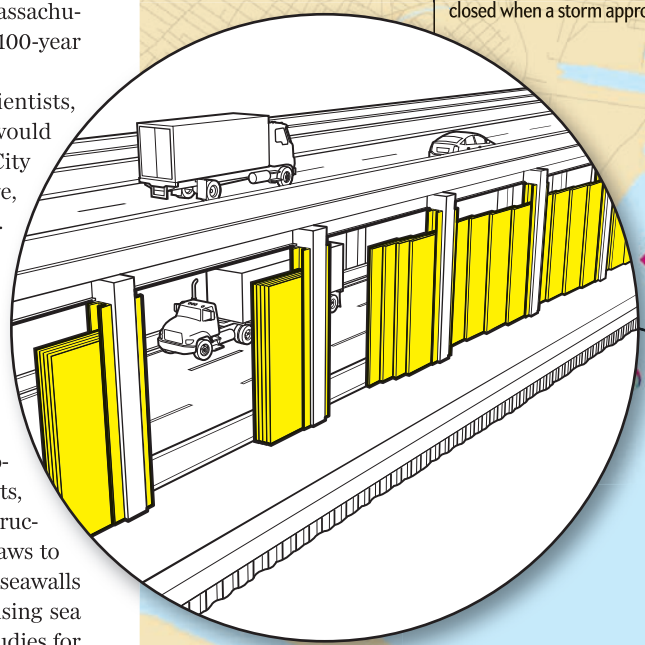
Flood Damage: Local Fixes Can Lessen Loss

As seas rise, tides and surges will invade farther into a coastal city, and even routine storms will cause more extensive flooding. Many street-level protection measures have been proposed for New York City and other municipalities; a variety of these proposals are shown here. Although quick implementation is tempting, experts warn that any mitigation measure should first meet standards and policies established in a region-wide protection plan, including a cost-benefit analysis for the short and long term. Otherwise, money could be wasted.



Install Retractable Floodwalls

If giant barriers are not built in the ocean outside a city to hold back a storm surge, high, retractable floodwalls could be installed between the pillars of a perimeter highway and closed when a storm approaches.



Frame Sidewalk Vents

Runoff from downpours can overtop the curb and flow into subway air vents that lie flush in sidewalks. Surrounding a vent with a simple vertical frame can divert the flow.

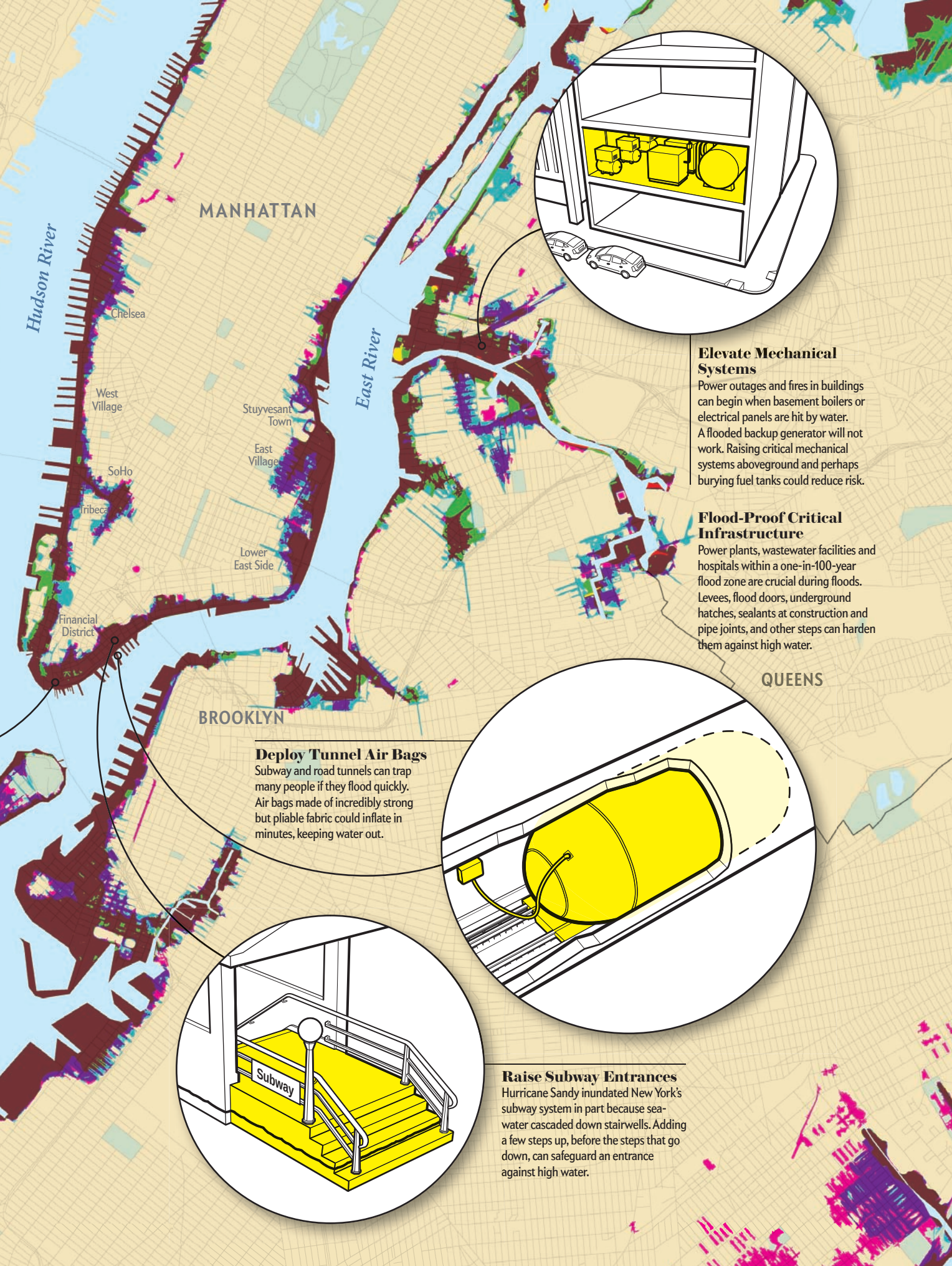
Bulk Up Boardwalks

Low-lying boardwalks and piers along the shore can be raised and fortified.

Erect Reefs

Artificial reefs or restored wetlands can break up waves and surges, reducing their energy.

Illustration by George Retseck (insets)



Elevate Mechanical Systems

Power outages and fires in buildings can begin when basement boilers or electrical panels are hit by water. A flooded backup generator will not work. Raising critical mechanical systems aboveground and perhaps burying fuel tanks could reduce risk.

Flood-Proof Critical Infrastructure

Power plants, wastewater facilities and hospitals within a one-in-100-year flood zone are crucial during floods. Levees, flood doors, underground hatches, sealants at construction and pipe joints, and other steps can harden them against high water.

Deploy Tunnel Air Bags

Subway and road tunnels can trap many people if they flood quickly. Air bags made of incredibly strong but pliable fabric could inflate in minutes, keeping water out.

Raise Subway Entrances

Hurricane Sandy inundated New York's subway system in part because seawater cascaded down stairwells. Adding a few steps up, before the steps that go down, can safeguard an entrance against high water.

Studies in Amsterdam. In the Netherlands, top-down management is a key to building and maintaining the world's most extensive flood-protection system. When Aerts realized that New York City's politics precluded such an approach, he and the city agreed to work separately. He continues to develop his blueprint, aiming for the end of May, parallel to the NPCC's deadline for reporting to Bloomberg. He is concerned that planners may shrink from recommending expensive barriers in a time of tight budgets and from recommending retreat from the shore.

Even if state and local governments were to accept Aerts's plan, it has its complications. For one thing, engineers would still have to agree on the best places to install the massive structures. A barrier is basically a wall that has enormous gates within it. The gates normally stay open to allow ships to pass and to allow the daily mixing of tides and freshwater from rivers that keeps a bay's ecosystem alive. When a storm comes, the gates close to hold back the surge.

Malcolm Bowman of Stony Brook University floated a plan several years ago for three barriers that would primarily protect Manhattan, but engineers are now leaning toward a two-barrier plan proposed by the commercial Halcrow Group that includes a five-mile-long span that would close off all of New York City [*see box on page 63*]. Although such a mammoth "outer harbor gateway" might sound crazy, in 2010 a barrier three times longer began operating in St. Petersburg, Russia. That $6.9-billion barrier is a good model because the water depths and land elevations in St. Petersburg are similar to those in New York City, says Jonathan Goldstick, an engineer and vice president at Halcrow, a lead consultant for the St. Petersburg installation.

Because gates remain open, barriers do nothing to deflect sea-level rise, so other measures would be needed for that threat. Critics also contend the water that a barrier holds back would flow to either side, making flooding worse in adjacent communities. But Philip Orton, an ocean engineer at Stevens Institute of Technology, says most of the reflected water spreads out across the sea. Before Sandy struck, he and his colleagues were running a computer model that re-creates the storm surge from Cape Cod to Maryland from Hurricane Irene. Orton can simulate barriers in different places to see how the surge responds. Tests of Bowman's three-barrier system showed that water alongside the gates would rise only an additional 5 to 7 percent. Orton is now adapting the model to Sandy's floodwaters.

Another concern is that barriers can become death traps. That's why Jacob is not a fan, even though they would have prevented Sandy from flooding his own house up the Hudson River from Manhattan. As barriers close off the bay around the city, the massive Hudson River, other rivers and heavy rainfall flowing into New York Bay would begin to fill it from behind the closed wall. Orton says the rate could be as high as three feet a day—but that is a lesser evil than an 11-foot surge. Most surges last only a matter of hours, so procedures would have to be in place to reopen the gates as soon as possible.

Huge barriers have proved effective in several places around the world. But one lesson the Dutch learned the hard way would have to be incorporated into any New York plan. They started building barriers in the 1950s and recently began to reengineer them at great cost to account for sea-level rise. New York would have to design barriers that can be raised over time—five feet in the ensuing 90 years, then more in the next century.

Likewise, new building codes to direct flood-proofing measures would have to take into account ongoing sea-level rise. Any adaptation plan should be even broader than that, says Sergej Mahnovski, director of the city's Office of Long-Term Planning and Sustainability. It should address all aspects of climate change, including longer heat waves and higher humidity that could seriously stress the electric grid, as well as stronger winds.

The main objection to barriers is cost. Yet the investment could pay off handsomely. Paul Kirshen, professor of environmental research and engineering at the University of New Hampshire, says every $1 spent in protection measures can prevent $4 in repairs after a storm, based on smaller-scale measures already implemented in various Northeast municipalities. Sandy cost New York City $19 billion in losses, according to Bloomberg. That's just one storm.

The main objection to barriers is cost. Yet the investment could pay off handsomely. Studies of past disasters show that every $1 spent on protection measures can prevent $4 in repairs after a storm.

Each city will have to assess its own unique threats and potential solutions. Because sea level in Norfolk, Va., the third-largest port on the East Coast, has risen 14 inches since the 1930s, its downtown area floods often. Miami might face the worst case. It is exposed to many more hurricanes than the Northeast, and unlike New York City almost all of it is at sea level. Moreover, the city is built on porous carbonate. When the sea lifts, the carbonate absorbs water, which rises up through the streets, flooding the city from the inside out. "How do you defend against that?" asks S. Jeffress Williams, a coastal marine geologist at the U.S. Geological Survey and the University of Hawaii. "I don't know." The city is expanding a pumping system that clears floodwater from rainstorms, but the system cannot pump the city out of a surge and would be useless for five feet of sea-level rise because the elevation of much of Miami is less than three feet.

PROTECTING THE EAST COAST

BARRIERS AND SEAWALLS might protect certain cities, but what can be done for the hundreds of miles of Jersey, Carolina or Florida beachfronts between them? Conventional measures such as man-made wetlands are inadequate. Wetlands that can absorb minor surges do not grow well along sloped shorelines exposed to open seas—and they offer no protection against sea-level rise. Swimming in muck doesn't thrill anyone, either. Piling up sand as an endless dune or a deep, rising beach is the only engineering option; however, "it's not clear there is enough quality sand" out on the continental shelf, Williams says.

Sand that has the right grain size to hold a beach against waves, much less storms, occurs in discrete deposits on the ocean floor, built up over thousands of years. Ships pump the

sand onto barges, which drop it on the shore, where workers spread it with trucks. This "beach nourishment" requires vast quantities of sand and money, and it's a losing game. As routine tides and storms relentlessly wash away beach sand, it fans out across the seafloor in thin layers that cannot be harvested.

Over time a higher ocean will wash away even more sand. "Could beach nourishment keep up with sea-level rise and surge for a few decades? Probably," says Robert Young, a geologist at Western Carolina University and an expert in beach nourishment. "Could we do it for 100 years? I don't think so."

For now, the U.S. Army Corps of Engineers, which mines and bulldozes much of the sand in question, will continue to replenish beaches every five to 10 years, according to Kathleen White, a senior environmental engineer there. Each episode can cost $1.5 million to $10 million per mile; New Jersey is at the high end. White says the corps is looking across a larger span of ocean for quality deposits, but she cannot say what it might find. Of course, the farther from shore the sand is, the more it costs to retrieve.

The entire pursuit is dubious in the long term, however. Beaches and barrier islands—which are wearing thin along the East Coast—are meant to slowly migrate landward, as very high tides or surges push sand from the ocean side toward the land side. The migration allows the beachfront to remain high and robust—nature's own storm protection. "The only reason for beach nourishment is to keep a beach line in place," Young says. The best way to preserve a beachfront is to let it move. Protective seawalls make matters worse over time. They stop the sand from migrating and reflect wave energy, so it scours away even more sand. "Erosion doesn't destroy beaches," Young says. "Seawalls and roads do, by getting in the way of natural beach relocation."

END THE PERVERSION

ALLOWING MIGRATION means people along the shore have to get out of the way. But perverse incentives encourage them to remain in high-risk areas.

Disaster recovery funds are one culprit. As long as Congress keeps authorizing them, people will keep rebuilding. The National Flood Insurance Program is another because the federal government subsidizes it. Individuals and businesses in flood zones do not pay anywhere near the full premiums. If they did, Aerts notes, "people would say, 'Oh, that is too high,' and they wouldn't build there."

Federal subsidies create "a moral hazard," Young maintains. "It's a totally false economy. It's bad fiscal policy, and it's bad federal policy—if we believe we should be adapting to climate change. I'm not suggesting we abandon the coast," he adds. "But it has to pay for itself."

After decades, Congress has just begun to change the program. Less subsidized premiums will be slowly phased in. A homeowner at the highest point in a floodplain might pay $800 a year, for example, but someone near the lowest point might pay $25,000. Gradually, people might opt to abandon the most expensive—and vulnerable—land.

It is still unclear if flood insurance subsidies will disappear entirely, and wealthy people could still choose to build in low-lying areas at their own financial risk, forcing municipalities to try to provide some form of public safety during storms. As an alternative, cities and states could buy out residents whose properties repeatedly flood. New York governor Andrew Cuomo said he would use $400 million of his state's federal disaster relief to offer such buyouts. Cas Holloway, deputy mayor for operations in New York City, says Sandy ruined about 500 homes there, and another 500 might have to be demolished.

If done over, say, 50 years, buyouts could clear the most vulnerable neighborhoods, leaving the land as a natural buffer.

RETREAT OR SWIM

BUYOUTS EPITOMIZE the ultimate solution to storm protection: retreat from the shore. But retreat is a tough sell. When Kirshen surveyed people who live in the low-lying East Boston community, they uniformly said they would not leave, even after recurrent flooding. They said the ocean is part of their identity. Rosenzweig, the Columbia climate scientist (who co-chairs the NPCC), adds that no adaptation plan can succeed "without taking the voices of neighborhoods into account."

Moving people is also politically unpopular. "Are we thinking about categorical retreat from the sea?" asks New York City deputy mayor Holloway rhetorically. "Absolutely not."

Yet retreat is under way elsewhere. The people and houses of Billingsgate Island off Cape Cod and of Hog Island off Virginia were moved to the mainland long ago. After a March 7 nor'easter ruined more than a dozen homes on Plum Island north of Boston, Massachusetts officials reiterated the state's policy of not allowing seawalls, saying that in the lowest-lying areas, moving homes to higher ground is the best option.

Jacob thinks that retreat in unavoidable and that discounting it is a form of risk denial. Policies need to be put in place to encourage people to move, he says. The Nature Conservancy, for example, is encouraging New York and other states to establish land trusts that can buy out a community, help it relocate, and allow the land to become a park or revert to a natural landscape.

The U.S.'s census of New York City, however, shows that even more people were living in low-lying areas in 2010 than in 2000. That trend is particularly befuddling, Jacob notes, because unlike Miami, much of New York City does lie well above sea level. With grim irony, he points out that "the city has a lot of cemeteries on high ground. We could switch the living and the dead, and probably the dead wouldn't mind." To him, that morbid plan might be a lesser evil than beachside residents drowning in a future storm.

Do leaders of cities and suburbs all along the coastal U.S. have the political will to do what's right for the long term? Or will they postpone the tough decisions and let nature force the consequences on residents later, at considerably more expense and suffering? SA

MORE TO EXPLORE

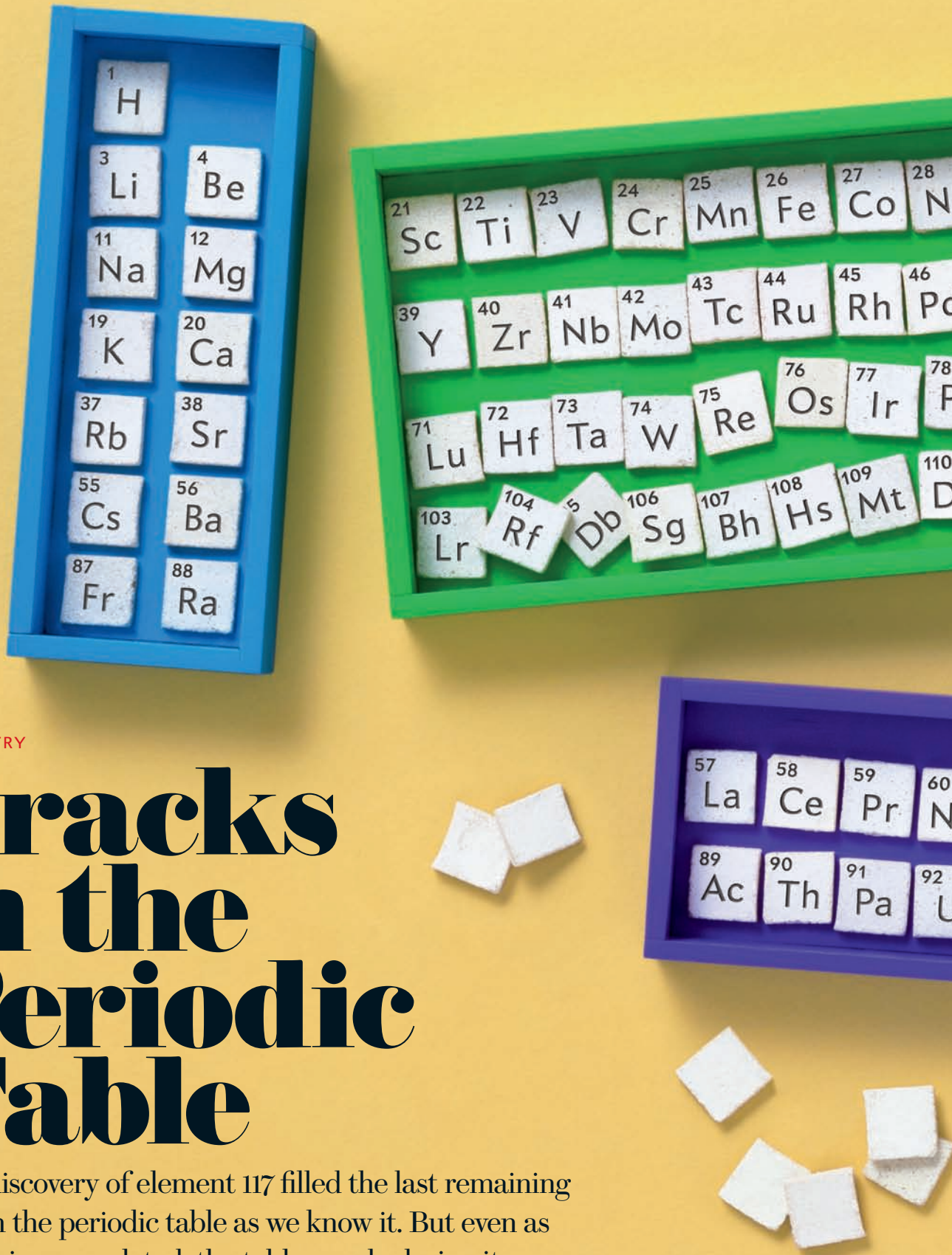
NY-NJ Outer Harbor Gateway. Presentation by Dennis V. Padron and Graeme Forsyth. March 31, 2009. Available as a PDF at http://bit.ly/XHwUSJ

Climate Change Adaptation in New York City: Building a Risk Management Response. New York City Panel on Climate Change in *Annals of the New York Academy of Sciences,* Vol. 1196; May 2010.

Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America. Asbury H. Sallenger, Jr., et al. in *Nature Climate Change,* Vol. 2, pages 884–888; December 2012.

SCIENTIFIC AMERICAN ONLINE

For a full explanation of why sea level could rise by five feet in New York City by 2100, see ScientificAmerican.com/jun2013/fischetti

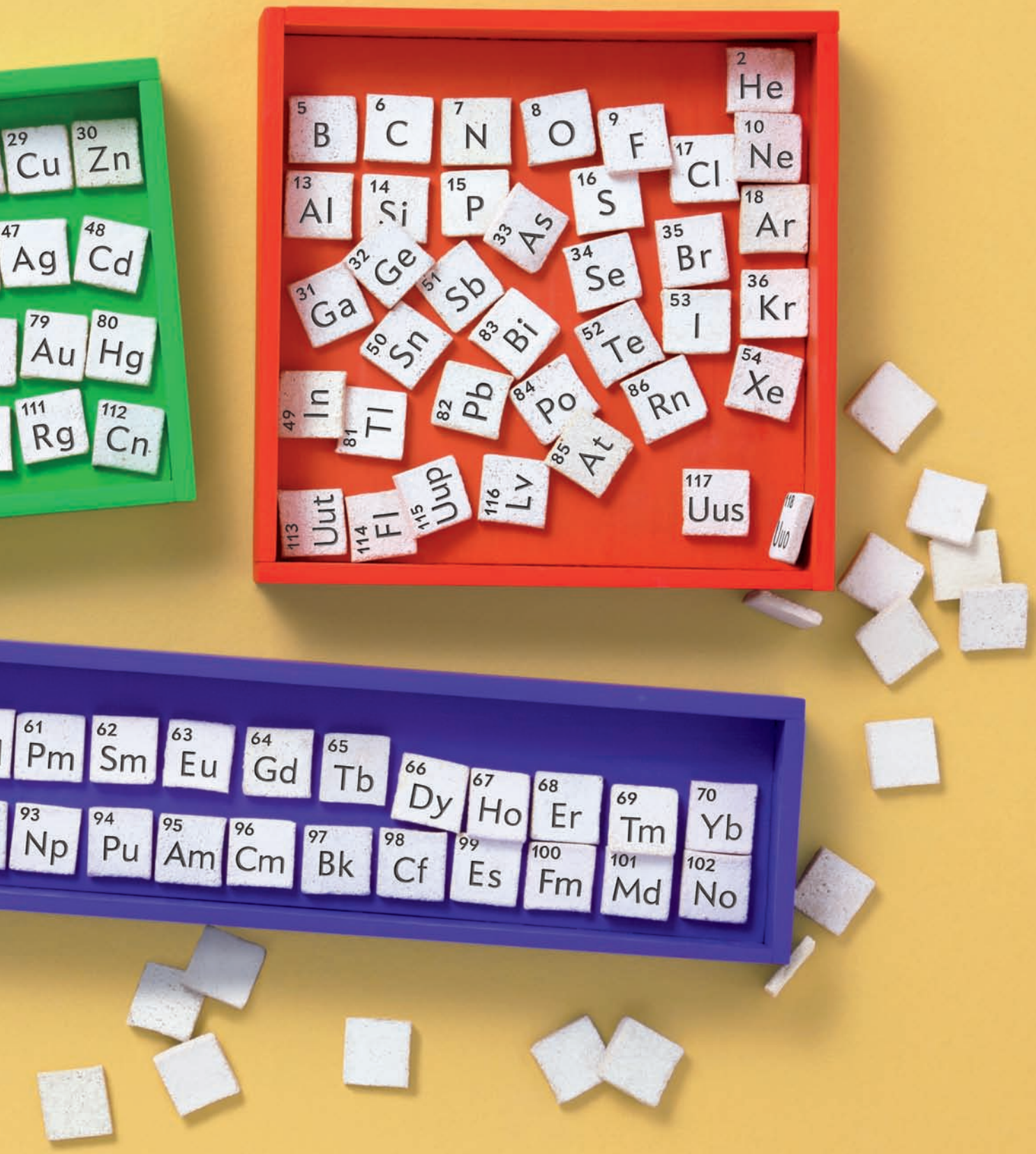


CHEMISTRY

Cracks in the Periodic Table

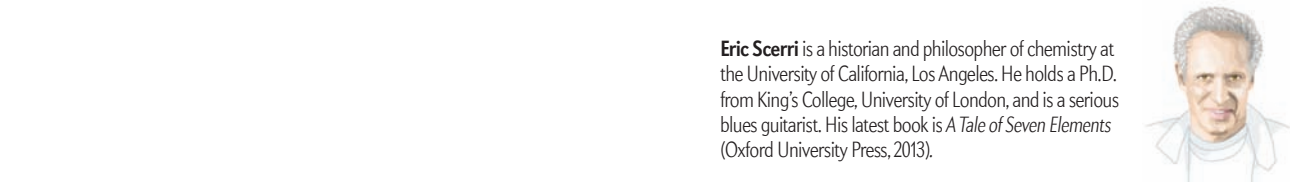
The discovery of element 117 filled the last remaining gap in the periodic table as we know it. But even as it is being completed, the table may be losing its power

By Eric Scerri



Photograph by Holly Lindem

Eric Scerri is a historian and philosopher of chemistry at the University of California, Los Angeles. He holds a Ph.D. from King's College, University of London, and is a serious blues guitarist. His latest book is *A Tale of Seven Elements* (Oxford University Press, 2013).





2010 RESEARCHERS IN RUSSIA ANNOUNCED THEY HAD SYNTHESIZED THE FIRST FEW NUCLEI of element 117. This new type of atom does not yet have a name, because the science community traditionally waits for independent confirmation before it christens a new element. But barring any surprises, 117 has now taken its permanent place in the periodic table of elements.

All elements up to 116, plus element 118, had been found previously, and 117 filled the last remaining gap in the bottom row. This achievement marks a unique moment in history. When Dmitri Mendeleev—also Russian—and others created the periodic table in the 1860s, it was the first grand scheme to organize all the elements known to science at the time. Mendeleev left several spaces blank in his table, and he made the bold guess that someday new elements would be discovered that would fill those blanks. Countless revisions of the table followed, but all of them had gaps—until now. With element 117, the periodic table is complete for the first time.

The ghost of Mendeleev would probably savor the triumph of his vision—for a while at least, until chemists and nuclear physicists synthesize the next few elements, requiring the addition of new rows and possibly leaving new gaps behind.

Even as the last few pieces of the puzzle were falling into place, however, something more fundamental was beginning to look amiss. And it might undermine the very rationale behind the table's existence: the recurring patterns that give the periodic table its name.

Mendeleev did not just predict the existence of elements yet to be seen; more remarkably, he correctly guessed their chemical properties, based on those recurring patterns. But as the atomic numbers—the number of protons in a nucleus—reached higher, some of the added elements no longer behaved the way the periodic law requires; that is, their chemical interactions, such as the types of bonds they form with other atoms, did not resemble those of other elements in the same column of the table. The reason is that some of the electrons orbiting the heaviest nuclei reach speeds that are a substantial fraction of the speed of light. They become, in physics parlance, "relativistic," causing the atoms' behavior to differ from what is expected from their position in the table. Moreover, predicting exactly how each atom's orbital structure will pan out is extremely challenging. Thus, even as Mendeleev's creation has filled up and scored its successes, it may have begun to lose its explanatory and predictive power.

A COMPLETE SUCCESS

ALTHOUGH MORE THAN 1,000 versions of the periodic table have been published so far, with variations in the arrangement of elements as well as in which elements they contained, all share one essential feature. When the elements are arranged sequentially, based on their atomic number (the first attempts used atomic weights instead), their chemical properties tend to repeat after a particular sequence of elements. For example, if we begin with lithium and move eight places ahead, we reach sodium, which has many similar features—both are metals soft enough to cut with a knife, and both react vigorously with water. If we then

IN BRIEF

The discovery of element 117 in 2010 completed for the first time the periodic table as we know it—at least until new discoveries will force chemists to extend it by adding a new row.

Some recent additions, however, may differ in their chemistry from the elements in the same column, breaking the periodic rule that had defined the table for a century and a half.

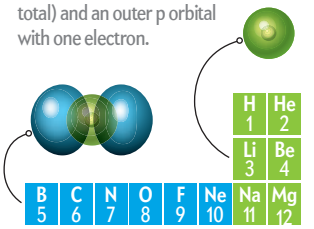
The surprising behavior may result from effects described by the special theory of relativity, which make some electron orbits tighter, among other effects.

Nuclear physicists continue in their quest to synthesize new elements, which will have new types of electron orbitals—and to understand their chemistry from studying a handful of short-lived atoms.

An Ever Growing Cabinet of Chemical Wonders

The periodic table organizes the elements according to recurring patterns in their chemical properties. Those properties are determined by the orbits of an atom's electrons about its nucleus, or "orbitals"—and specifically by the outermost orbitals. Going from lower atomic numbers to higher ones, the structures of the outer orbitals change in a recurring, or periodic, way. For instance, elements 5 to 10 have outer orbitals of a family called p, and those repeat again for elements 13 to 18—all these elements therefore belong to the same "p-block" (*blue*).

Sample structures: Lithium (Li) has two s orbitals, containing three electrons (*not shown*) in total. Boron (B) has two s orbitals (four electrons total) and an outer p orbital with one electron.



New Kid, New Block

This form of the periodic table is called the Janet left-step table, after Charles Janet. Its bottom row will be completed with the discovery of elements 119 and 120, whose outer orbitals are s type. Element 121 will be the first to have orbitals of a new family, called g type, and it will therefore take its place in an entirely new block (*bottom left*).

																	H 1	He 2													
																	Li 3	Be 4													
												B 5	C 6	N 7	O 8	F 9	Ne 10	Na 11	Mg 12												
												Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	K 19	Ca 20												
Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	Rb 37	Sr 38														
Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	Cs 55	Ba 56														
La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86	Fr 87	Ra 88
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	Uut 113	Fl 114	Uup 115	Lv 116	Uus 117	Uuo 118	119	120
121	122																														
G-block		F-block												D-block										P-block						S-block	

Every two periods, and thus every two rows in the table, a new family of electron orbitals appears. Shown at the right are examples of orbital shapes, one for each family.



move a further eight places ahead, we reach potassium, which is also soft and reactive with water, and so on.

In the earliest periodic tables, including those designed by Mendeleev but also by others, the length of each period—and thus the length of each row—was always eight. Soon, however, it became clear that the fourth and fifth periods repeated not after eight elements but after 18. Correspondingly, the fourth and fifth rows of the table were wider than the previous ones to accommodate the extra block of elements (the transition metals, which in the familiar view of the periodic table, sit in the middle). The sixth period turned out to be even longer, containing 32 elements, because of the inclusion of a series of 14 elements called the lanthanides—more recently renamed as lanthanoids.

In 1937 nuclear physicists began to synthesize new elements, starting with technetium. It filled one of four gaps in the table then known, which extended from 1 (hydrogen) to 92 (uranium). The other three missing pieces soon followed, two of them synthesized (astatine and promethium) and the third found in nature (francium). But even as those gaps were being filled, new discoveries were being added to the periodic table beyond uranium, leaving new gaps.

American chemist Glenn Seaborg realized that actinium, thorium and protactinium, together with uranium and the following 10 elements, were part of a new series, which, like the lanthanoids, had 14 elements and which became known as the actinides, or actinoids. (Because the extra elements in these two series would make the table even wider, standard periodic tables display the two 14-element series in a separate block at the bottom.)

As scientists realized in the first half of the 20th century, the periodicity of the elements is rooted in quantum physics and, in particular, in the physics of how electrons orbit the nucleus. The orbits of electrons come in a discrete range of shapes and sizes. Atoms with larger atomic numbers have the same orbit types, or "orbitals," as those of lower numbers, while adding new types. The first period has one type only, named s, which can be occupied by one or two electrons (one for hydrogen; two for helium). The second and third periods each add one more s-type orbital, plus three orbitals of a new type, p. Again, each of these four orbitals can be occupied by one or two electrons, for a potential total of eight electrons—which gives rise to the periodicity of eight in the original versions of the table. The fourth and fifth periods have, in addition to the s and p types, a third kind, d, which adds an extra 10 places for the electrons and thus stretches periods to 18. Finally, the last two cycles have orbitals of types s, p, d and f and have a length of 32 elements (18 + 14).

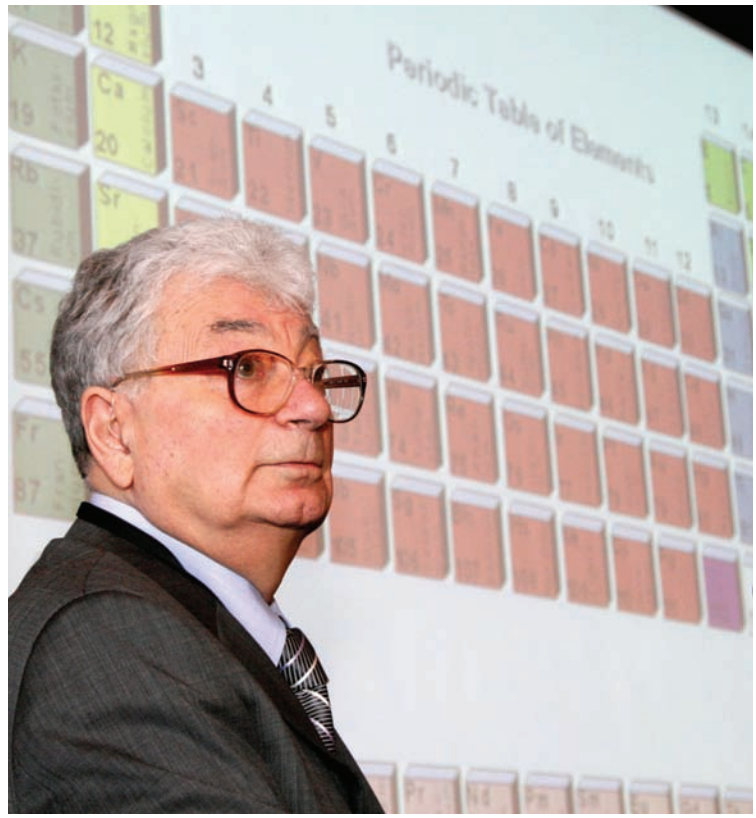
When Yuri Oganessian and his collaborators at the Joint Institute for Nuclear Research near Moscow announced they had synthesized the elusive element 117, all elements in the last row were now in place. The intimate connection between the structure of the table and that of atoms means that the comple-

Illustration by Jen Christiansen

tion of the table was not purely a matter of aesthetics or of organizing information on paper. Element 118 is the only one that has all its s, p, d and f orbitals filled with electrons.

If more elements are ever synthesized, they will take their place on an entirely new row of the table. Element 119, the one that is most likely to appear next [*see box on preceding page*], would start a new cycle—again with the simplest type of orbital, the s orbital. Element 119 and the following element 120 would occupy the first two slots in the new eighth period. But with element 121, a wholly new block would start, at least in principle, which would involve orbitals never encountered before: the g orbitals. As before, the new orbital types add new possibilities for the electrons and thus lengthen the periodicity, raising the number of columns. This block of elements would broaden the table to as many as 50 columns (although chemists have already devised more compact ways of arranging such an expanded table).

A completed table—one with all its rows filled in—would seem to be the ultimate fulfillment of Mendeleev's dream. And it might have been, were it not for Albert Einstein and his special theory of relativity.



YURI OGANESSIAN led the team that created element 117 and is now set to attempt the synthesis of the next novel element, 119.

BREAKING BAD?

AS WE MOVE FROM LOWER to higher atomic numbers, nuclear charge increases because of the additional protons. As nuclear charge increases, so does the speed of the electrons in the inner orbitals—to the point that the special theory of relativity begins to play a bigger role in explaining their behavior. This effect causes a contraction in the size of the inner orbitals and makes them more stable. That tightening has a knock-on effect on the other s and p orbitals, which also tighten, including the "valence" orbitals, the outermost ones, which govern the chemical properties.

All these phenomena come under the name of the direct relativistic effect, which, broadly speaking, increases with the charge on the nucleus of each atom. Some competing effects, however, make things more complicated. Whereas the direct relativistic effect stabilizes certain orbitals, another, "indirect" relativistic effect destabilizes the d and f orbitals. It is a kind of electrostatic screening by the s and p electrons, whose negative charges partially neutralize the attraction from the positive charge of the nucleus as measured from farther out. Thus, to distant electrons the nucleus appears to have less, not more, electrostatic pull.

Some relativistic effects on elements are apparent in everyday life. For example, they explain the color of gold, which sets it apart from the colorless elements surrounding it in the d-orbital block of the periodic table—such as silver, which lies directly above gold.

An atom of a d-block metal, when hit by a photon of the right wavelength, undergoes a transition. It absorbs the photon, and the photon's energy makes an electron jump from a d orbital to the s orbital directly above it. In silver, this gap between orbital energies is rather large, so that it takes a photon in the ultraviolet region of the spectrum to trigger the transition. But photons in the spectrum of visible light, having lower energy than ultraviolet rays, just bounce off, so that to our eyes the material appears to act as a nearly perfect mirror.

In gold, the relativistic contraction lowers the energy of the s orbitals even as it raises the energy of the d orbitals, thus narrowing the gap between the two levels. Now the transition requires less energy—exactly that carried by a photon in the blue part of the spectrum. Photons of all other colors still bounce off, however, and we observe white light minus blue light—which yields the characteristic golden-yellow color.

Pekka Pyykkö of the University of Helsinki and others went on to predict a number of effects that relativity has on gold, including the fact that it could bind to other atoms in surprising new ways. The compounds they expected to result from such interactions were subsequently discovered, a feat that somewhat paralleled the exploits of Mendeleev in anticipating new elements. Pyykkö's successful predictions included bonds between gold and the noble gas xenon—which is usually extremely inert—and triple bonds between gold and carbon. Another success was a spherical molecule involving one atom of the metal tungsten and 12 atoms of gold and resembling the all-carbon "fullerenes," better known as buckyballs. This gold fullerene forms quite spontaneously when tungsten and gold are vaporized in the presence of helium gas.

Relativistic quantum-mechanical calculations have also proved indispensable in studying how gold clusters can act as catalysts—for example, to break down toxic chemicals typical of car exhaust—even though bulk gold is notoriously inert.

COURTESY OF FLEROV LABORATORY

SUPERHEAVY SURPRISES

EVEN WITH THE EMERGENCE of relativistic effects, elements such as gold still do not deviate too far from the character expected. Until recently, novel elements by and large matched the properties that were anticipated based on their position in the periodic table. But worse (or perhaps more interesting) surprises were yet to come. Some tests on the chemistry of the most recently discovered elements have begun to show what could be serious cracks in the periodic law.

Using particle accelerators to smash heavy nuclei together, nuclear physicists are able to produce "superheavy" elements—those beyond atomic number 103. Early experiments in the 1990s on rutherfordium (104) and dubnium (105) already suggested that these elements did not have the properties expected for them according to their positions in the periodic table. For example, Ken Czerwinski and his colleagues at the University of California, Berkeley, found that in solution, rutherfordium reacted in ways similar to plutonium, an element that is quite distant in the periodic table. Similarly, dubnium was showing signs of behaving more like the element protactinium, which is again rather distant in the periodic table. According to the periodic law, these two elements should have behaved instead like those directly above them in the periodic table, namely, hafnium and tantalum.

In more recent work, scientists have been able to synthesize new superheavy elements in only extremely small numbers: the discovery of element 117 was based on the observation of just six atoms. Superheavy elements also tend to be very unstable, decaying into lighter elements in a fraction of a second. Experts mostly are left to observe the debris of this nuclear decay, which yields information on the physics and chemistry of their nuclei. In this state of affairs, investigating chemical properties through traditional "wet" chemistry—put the stuff into a flask and watch it react with other chemicals—is out of the question. And yet scientists have come up with ingenious techniques to study the chemistry of these elements one atom at a time.

Chemical experiments carried out on the next two elements were, compared with those on 104 and 105, disappointing. Seaborgium (106) and bohrium (107) seemed to act just the way Mendeleev would have guessed, inspiring researchers to give titles such as "Oddly Ordinary Seaborgium" and "Boring Bohrium" to their scholarly papers. The periodic law seemed to be back in business.

In the case of element 112, chemists and physicists have been trying to assess whether the element behaves more like mercury, which sits directly above it in the periodic table, or like the noble gas radon, as some relativistic calculations predict. In such experiments, teams synthesize atoms of 112, along with some heavy isotopes of mercury and radon. (Although mercury and radon occur naturally in substantial amounts, investigators use synthetic ones because they can produce them in conditions identical to those that give rise to the heavier elements, rather than relying on data that apply to the macroscopic properties of the more abundant lighter elements.)

The experimenters then allow all these atoms to deposit on a surface kept at very low temperature and coated partly with gold and partly with ice. If element 112 truly behaves like a metal, it will bind to gold. If it is more like the noble gas radon, it will tend to deposit on the ice. To date, different laboratories have obtained different results, and the situation is still far from settled.

The effects of relativity on element 114 also remain to be seen. Initial results reported by Robert Eichler and his group at the Paul Scherrer Institute in Switzerland indicate some genuine surprises here, given that the disagreement with the theory is quite pronounced.

It is not clear yet whether the principle that elements in the same column in the periodic table behave similarly remains valid for very heavy atoms.

New additions to the periodic table will surely follow, and research into the chemistry of those elements will help clarify the dilemma. A more general question is whether there is an end to the periodic table. The overall consensus is that when the number of protons becomes too large, nuclei will not form, even for a fleeting instant. But opinions seem to differ as to where the new elements will stop. In calculations that assume the nucleus is pointlike, the limit appears to be at element 137. Other experts who have taken account of the volume of the nucleus estimate the final element to have an atomic number of 172 or 173.

It is simply not yet clear whether the principle that elements in the same column in the periodic table behave similarly remains valid for very heavy atoms. That question is of no great practical consequence, at least for the foreseeable future. The loss of predictive power in the superheavy realm will not affect the usefulness of the rest of the table. And the typical chemist will never get to play with any of the elements of highest atomic numbers: these elements' nuclei are all very unstable, which means that they decay into lighter elements instants after being created.

Still, the question of special relativity's effect strikes at the very heart of chemistry as a discipline. If the periodic law does lose its power, then chemistry will be in a sense more reliant on physics, whereas a periodic law that holds up would help the field maintain a certain level of independence. In the meantime, perhaps, Mendeleev's ghost should just kick back and marvel at the success of his favorite brainchild. SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE

See a slide show of the many shapes the periodic table has taken throughout history, plus more multimedia content, at **ScientificAmerican.com/jun2013/periodic-table**





BRYAN NASH GILL, AUTHOR OF *WOODCUT*; PRINCETON ARCHITECTURAL PRESS, NEW YORK CITY, 2012

BOTANY

RING CYCLE

Trees tell a tale of changing climate

By Marissa Fessenden

LIKE MANY BIOLOGICAL FORMS, TREE RINGS SPEAK TO THE IMAGINATION of both artists and scientists. To create the image at the left, Connecticut-based artist Bryan Nash Gill took a cross section of a fallen willow tree, sanded it smooth and then charred it to raise the grain. Next, he rolled ink over the wood and laid down a piece of paper to transfer the pattern. Gill's work is a way of "making the wood sing," he says.

For dendrochronologists—scientists who analyze tree rings—each tree's story can add up to a narrative about past climate. This willow's rings have varying widths, which suggests that some years were favorable for growth and others were less so, says Connie Woodhouse, associate professor in the School of Geography and Development at the University of Arizona. The rippled rings on the right are part of a burl—an abnormal growth possibly created by some kind of infection. She also notes that the tree has two centers, which means it may have begun its life as a twin and later the siblings fused.

Also visible in the print are seasonal growth patterns. Gill's charring process burns away the lighter, softer earlywood from spring growth and leaves behind the harder, denser latewood from summer growth. In her work, Woodhouse measures the latewood to track changes in summer monsoon rains that sweep across Arizona and New Mexico. In a study published online in March in *Geophysical Research Letters,* Woodhouse and her colleagues analyzed 470 years of tree ring data. The researchers found that mega droughts used to be more intense and longer-lasting than they have been over the past century, although that is small comfort to farmers enduring the ongoing drought gripping the West. SA

Marissa Fessenden *is a freelance science writer based in Brooklyn, N.Y.*

SCIENTIFIC AMERICAN ONLINE

View a video about dendrochronology at ScientificAmerican.com/jun2013/tree-rings



PSYCHOLOGY

Armor against Prejudice

Even subtle reminders of prejudice against one's sex, race or religion can hinder performance in school, work and athletics. Researchers have found new ways to reverse and prevent this effect

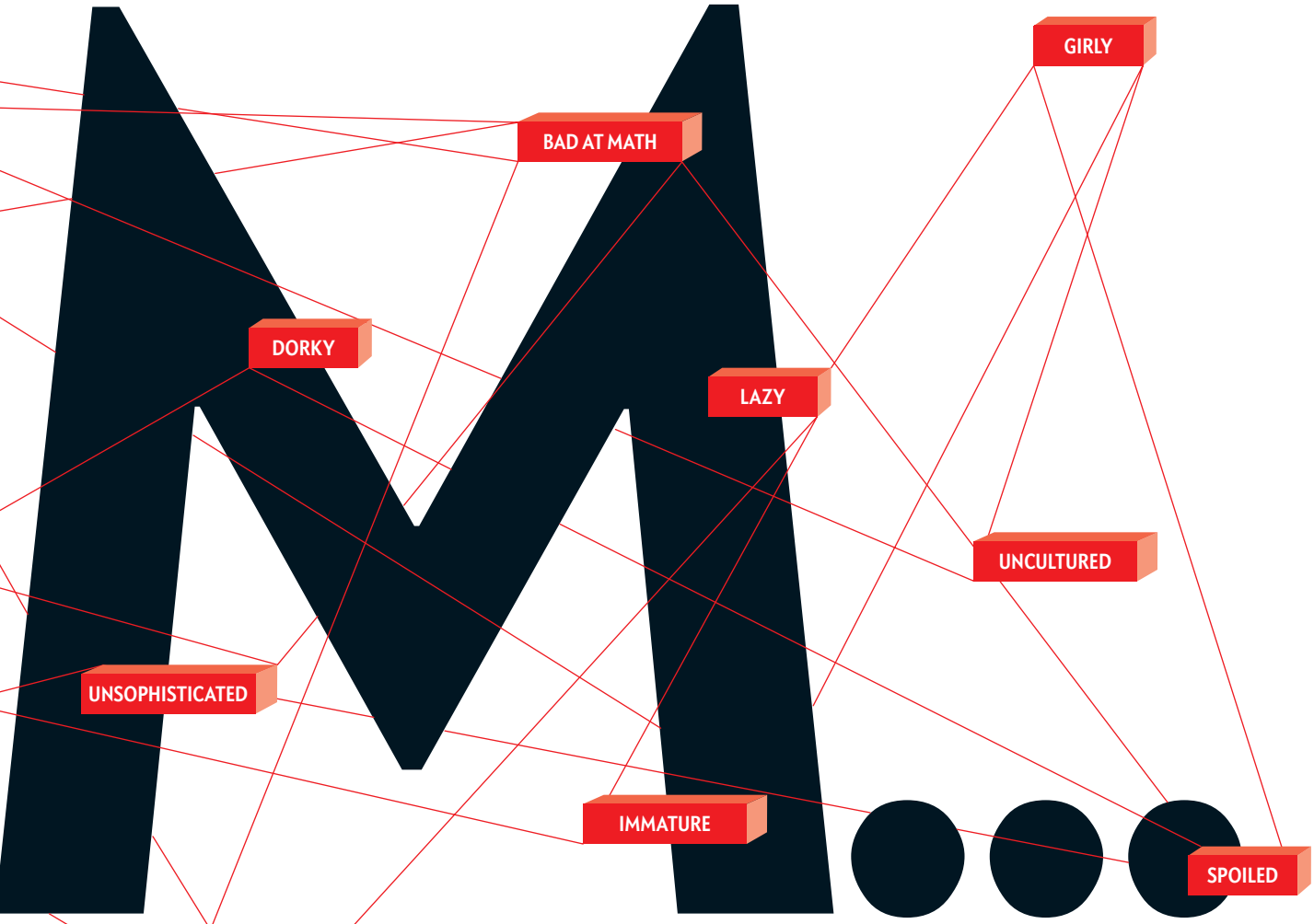
By Ed Yong

IN BRIEF

Stereotype threat, the fear of failing in a way that reinforces derogatory stereotypes of one's social group, undermines performance in school, sports and the workplace.

Recently researchers have developed a more sophisticated understanding of how such anxiety arises, how to combat it and how to prevent it from occurring in the first place.

Relatively simple and brief confidence-boosting exercises shrink academic achievement gaps. Educators are now scaling up these interventions to statewide programs.



NEIL DEGRASSE TYSON, THE RENOWNED SCIENCE COMMUNICATOR, EARNED HIS PH.D. IN ASTROPHYSICS from Columbia University in 1991. About 4,000 astrophysicists resided in the country at the time. Tyson brought the total number of African-Americans among them to a paltry seven. In a convocation address, he spoke openly about the challenges he faced:

"In the perception of society … my academic failures are expected and my academic successes are attributed to others," Tyson said. "To spend most of my life fighting these attitudes levies an emotional tax that is a form of intellectual emasculation. It is a tax that I would not wish upon my enemies."

Tyson's words speak to a broad truth: negative stereotypes impose an intellectual burden on many minorities and on others who think that the people around them perceive them as inferior in some way. In many different situations—at school, at work or in sports stadiums—these individuals worry that they will fail in a way that affirms derogatory stereotypes. Young white athletes fear that they will not perform as well as their black peers, for example, and women in advanced math classes worry that they will earn lower grades than the men. This anxiety—Tyson's "emotional tax"—is known as stereotype threat. Hundreds of studies have confirmed that stereotype threat undermines performance, producing the very failure they dread. Sometimes people become trapped in a vicious cycle in which poor performance leads to more worry, which further impedes performance.

In recent years psychologists have greatly improved their understanding of how stereotype threat affects individuals, why it happens and, most important, how to prevent it. Although the threat is real, some

researchers question how well some of the relevant laboratory studies mirror anxiety in real-world settings; they also note that it is just one of many factors that contribute to social and academic inequality. Yet it is also one of the factors that can be easily changed. In studies conducted in actual schools, relatively simple interventions—such as self-esteem-boosting writing exercises completed in less than an hour—have produced dramatic and long-lasting effects, shrinking achievement gaps and expelling stereotype threat from the classroom and students' minds. Some educators are working on ways to scale up these interventions to statewide education programs.

Ed Yong is a science writer based in England. He has written for *Nature*, *Wired*, *National Geographic* and *New Scientist*, among other publications.



IDENTIFYING THE THREAT

TWO PSYCHOLOGISTS, Claude Steele of Stanford University and Joshua Aronson, then also at Stanford, coined the term "stereotype threat" in 1995. Then, as now, black students across the U.S. earned worse grades on average than their peers and were more likely to drop out early at all levels of education. The various explanations for this gap included the pernicious idea that black students were innately less intelligent. Steele and Aronson were not convinced. Instead, they reasoned, the very existence of this negative stereotype might impair a student's performance.

In a now classic experiment, they presented more than 100 college students with a frustrating test. When they told the students that the exam would not measure their abilities, black and white students with comparable SAT scores did equally well. When Steele and Aronson told the students that the test would assess their intellectual ability, however, the black students' scores fell, but those of their white peers did not. Simply asking the students to record their race beforehand had the same effect.

The study was groundbreaking. Steele and Aronson showed that standardized tests are far from standardized. When presented in a way that invokes stereotype threat, even subtly, they put some students at an automatic disadvantage. "There was a lot of skepticism at first, but it's reducing with time," Aronson says. "In the beginning, even I didn't believe how strong the effects were. I thought, 'Somebody else has to replicate this.'"

Many researchers have. To date, hundreds of studies have found evidence of stereotype threat in all manner of groups. It afflicts students from poorer backgrounds in academic tests and men in tasks of social sensitivity. White students suffer from it when pitted against Asian peers in math tests or against black peers in sports. In many of these studies, the strongest students suffer the greatest setbacks. The ones who are most invested in succeeding are most likely to be bothered by a negative stereotype and most likely to underperform as a result. Stereotype threat is nothing if not painfully ironic.

Exactly how pervasive stereotype threat is in real-world settings remains somewhat unclear, however, largely because the relevant studies face the same problems that plague much of social psychology. Most were conducted with small numbers of college students—which increases the chances of statistical flukes—and not all studies found a strong effect. Some critics also note that laboratory experiments are often a poor substitute for the real world. Paul Sackett of the University of Minnesota has argued that outside the lab, stereotype threat could be less common and more easily overcome. Last year Gijsbert Stoet, then at the University of Leeds in England, and David C. Geary of the University of Missouri–Columbia examined every study that looked for stereotype threat among women taking math tests—a phenomenon that Steele and his colleagues first identified in 1999. Out of 20 that repeated the 1999 experiment, only 11 concluded that women performed worse than men. Geary is not ready to discount stereotype threat, but he thinks it may not be as strong as it is sometimes portrayed.

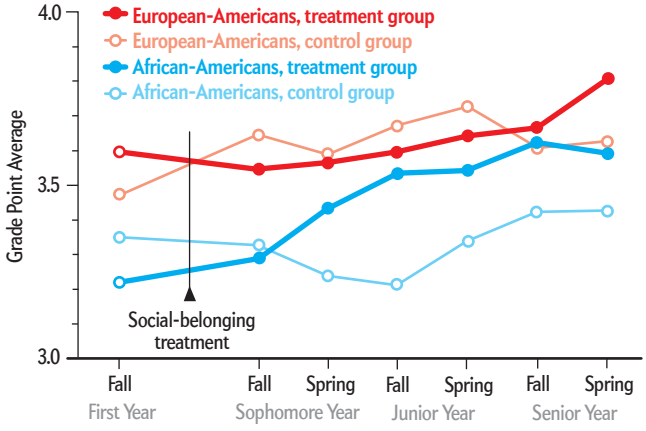
Ann Marie Ryan of Michigan State University has identified some plausible reasons for such inconsistent conclusions. In 2008 she and Hanna-Hanh Nguyen, then at California State University, Long Beach, compared the results of 76 different studies on stereotype threat in high schoolers and undergraduates. They found that in the lab, scientists are able to detect the threat only under certain conditions, such as when they give volunteers an especially difficult test or when they work with people who strongly identify with their social group.

In the past decade psychologists have shifted from showing that stereotype threat exists to understanding how it works. Researchers have demonstrated that the threat operates in the same way across different groups of people. Anxiety arrives; motivation falls; expectations lower. Building on these findings, Toni Schmader of the University of British Columbia surmised that the threat preys on something fundamental. The most obvious culprit was working memory—the collection of cognitive skills that allows us to temporarily hold and manipulate information in our mind. This suite of skills is a finite resource, and stereotype threat can drain it. Individuals might psychologically exhaust themselves by worrying about other people's prejudices and thinking about how to prove them wrong. To test this idea, Schmader gave 75 volunteers a difficult working memory test, during which they had to memorize a list of words while solving mathematical equations. She told some volunteers that the test would assess their memory skills and that men and women may have inborn differences in their abilities. Sure enough, women who were told of this supposed discrepancy kept fewer words in mind, whereas their male colleagues had no such problems.

This depletion of working memory creates various stumbling blocks to success. People tend to overthink actions that would otherwise be automatic and become more sensitive to cues that might indicate discrimination. An ambiguous expression can be misread as a sneer, and even one's own anxiety can become a sign of imminent failure. Minds also wander, and self-control weakens. When Schmader stopped women in the middle of a math test and asked them what they were thinking of, those under stereotype threat were more likely to be daydreaming.

EXPELLING STEREOTYPES

MOST RECENTLY, researchers have moved the study of stereotype threat out of the lab and into schools and lecture halls, where they try to dispel or prevent the threat altogether. "I see three waves of research," Schmader says. "The first was identifying the phenomenon and how far it travels. The second was looking



ANXIETY ABOUT FITTING IN at college can hinder some minorities' academic performance. In one study, European- and African-American freshmen read surveys emphasizing that such concerns are universal and transient. By increasing feelings of belonging, this simple exercise narrowed the academic gap between the two groups by 79 percent over the next three years.

at who experiences the effect and its mechanisms. The third wave is now to translate these results into interventions."

Geoffrey Cohen, also at Stanford, has achieved particularly impressive results. His method is disarmingly simple: he asks people to consider what is important to them, be it popularity or musical ability, and write about why it matters. The 15-minute exercise acts like a mental vaccine that boosts students' self-confidence, helping them combat any future stereotype threat.

In 2003 Cohen visited racially diverse middle schools in California and put his exercise through a randomized controlled trial—the gold-standard test in medicine that checks if an intervention works by pitting it against a placebo. Cohen administered his exercise to seventh graders: half wrote about their own values, and the rest wrote about things that were unimportant to them. The trial was double-blinded, meaning that neither Cohen nor the students knew who was in which group.

At the end of the term, black students who completed the exercise had closed a 40 percent academic gap between them and their white peers. Best of all, the students at the bottom of the class benefited most. Over the next two years the same students took two or three booster versions of the original exercise. Only 5 percent of the poorest students who wrote about their values ended up in remedial classes or repeated a grade, compared with 18 percent of those in the control group. Ultimately, the black students' grade point averages rose by a quarter of a point and by 0.4 point among the worst performers.

A few fractions of a point here and there might not seem like a huge improvement, but even small changes in confidence—whether positive or negative—have a cumulative effect. Children who do poorly at first can quickly lose self-confidence or a teacher's attention; conversely, signs of modest progress can motivate far greater success. By intervening early on, Cohen asserts, educators can turn vicious cycles into virtuous ones.

Cohen's task is so simple that Ryan and others are not entirely convinced by his results. "It was hard for us to believe, but we've replicated it since," Cohen says. In the past five years he has used his exercise to swing the fortunes of black students in three different middle schools and to largely close the gender gap in a college-level physics class. Skeptics, though, still hope that independent researchers will try to replicate these studies.

Meanwhile Cohen is seeking new ways to help students. He has collaborated with Greg Walton, also at Stanford, to counter a kind of isolation that stereotype threat often induces. Many minorities worry that their academic peers will not fully accept them. Walton combated these worries with survey statistics and quotes from older students showing that such feelings are common to everyone regardless of race and that they disappear with time. "It makes them reframe their own experiences through the lens of this message, rather than of race," Walton explains.

Walton and Cohen tested their hour-long exercise with college students in their first spring term. Three years later, when the students graduated, the achievement gap between blacks and whites had been halved. The black students were also happier and healthier than their peers who did not take part in Walton's exercise. In the past three years they had made fewer visits to the doctor. Walton acknowledges that such a simple exercise may look trivial to an outsider. But, he says, for a students who are "actively worried about whether they fit in, the knowledge that those concerns are shared and temporary is actually very powerful."

Cohen and Walton are now scaling up their simple and inexpensive interventions from individual schools to entire states. The pair—as well as Carol Dweck and Dave Paunesku—both also at Stanford, created PERTS (the *P*roject for *E*ducation *R*esearch *T*hat *S*cales), which allows them to rapidly administer their interventions online. They can also combine the programs or pit them against one another to see which have the greatest effects.

Even if the programs work as planned, researchers who study stereotype threat admit that undoing it is not a panacea against inequality. Cohen, for example, tested his initial writing exercise only in schools with mixed ethnicities, and he is unsure if it would work in predominantly minority schools. "There are many reasons why we have achievement gaps—inequality of resources, bad schools, less well-trained teachers," Walton adds. "There doesn't seem to be much hope of addressing these structural barriers. What's exciting about stereotype threat is that we can make headway in the face of those things."

Recent work on the phenomenon not only offers realistic hope for alleviating some truly tenacious problems—it also upends pervasive beliefs. By thwarting stereotype threat, researchers have shown that the stereotypes themselves are unfounded. Performance gaps between black and white students or between male and female scientists do not indicate differences in ability; rather they reflect prejudices that we can change. "The things we thought were so intractable 15 years ago aren't," Aronson says, "and that's a hugely positive message." SA

MORE TO EXPLORE

Recursive Processes in Self-Affirmation: Intervening to Close the Minority Achievement Gap. Geoffrey L. Cohen et al. in *Science,* Vol. 324, pages 400–403; April 17, 2009.

A Brief Social-Belonging Intervention Improves Academic and Health Outcomes of Minority Students. Gregory M. Walton and Geoffrey L. Cohen in *Science,* Vol. 331, pages 1447–1451; March 18, 2011.

SCIENTIFIC AMERICAN ONLINE

To learn more about the effort to scale up social interventions that counteract stereotype threat, visit Scientific American.com/jun2013/stereotype-interventions

SOURCE: "A BRIEF SOCIAL-BELONGING INTERVENTION IMPROVES ACADEMIC AND HEALTH OUTCOMES OF MINORITY STUDENTS," BY GREGORY M. WALTON ET AL., IN *SCIENCE,* VOL. 331; MARCH 18, 2011

Graphic by Jen Christiansen

INFORMATION TECHNOLOGY

Edge of the Internet

To keep the Web from collapsing under the weight of ever more data, the network needs to radically change the way it handles information, says the head of Bell Labs Research

Interview by Larry Greenemeier

IN BRIEF

WHO
MARKUS HOFMANN

VOCATION | AVOCATION
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Bell Labs Research, Holmdel, N.J.

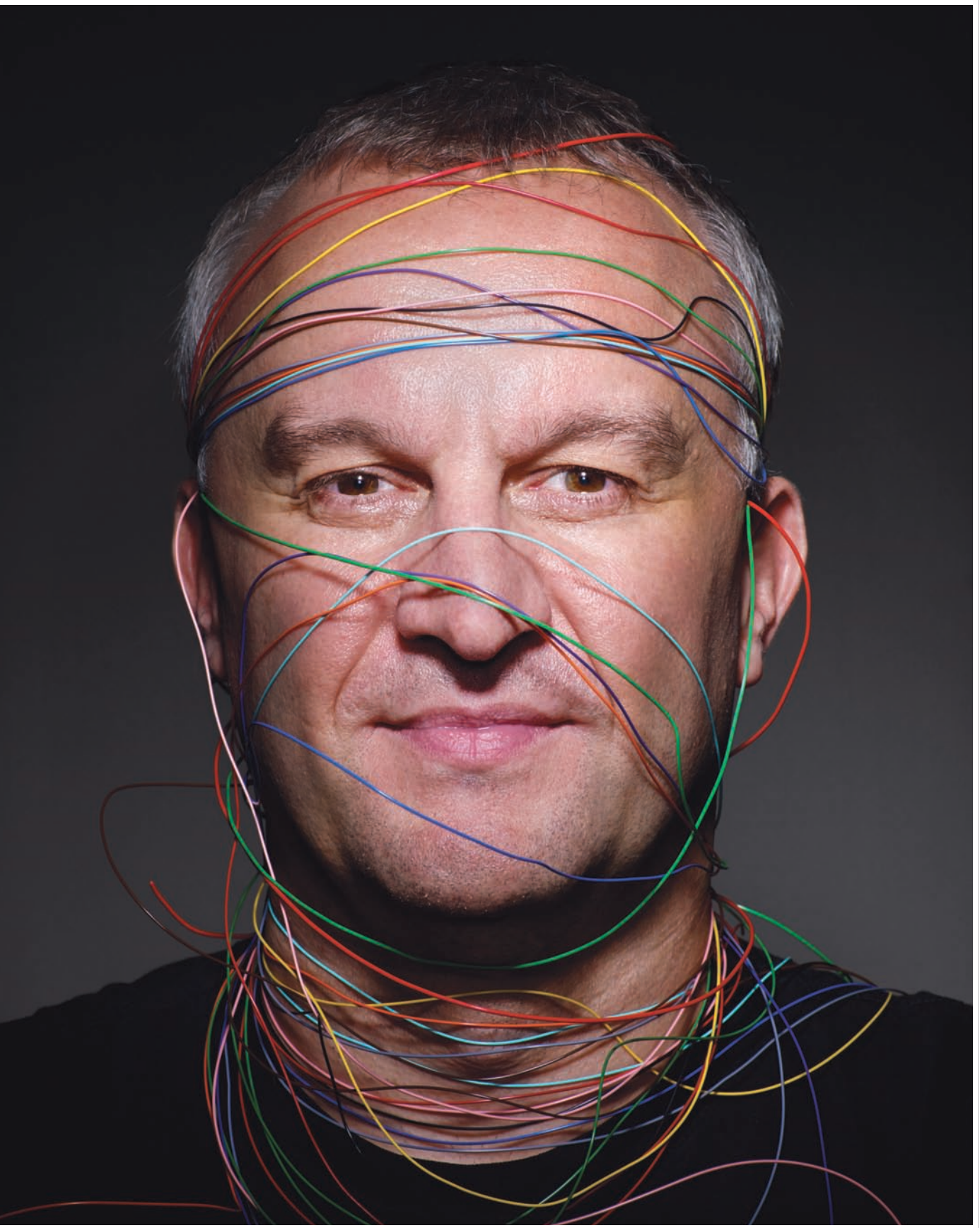
RESEARCH FOCUS
Will smarter communications networks help the Internet through its growing pains?

BIG PICTURE
The Internet and its underlying infrastructure must accommodate heavier data traffic generated by mobile devices and multimedia content.

THE NUMBER OF SMARTPHONES, TABLETS AND OTHER NETWORK-CONNECTED gadgets will outnumber humans by the end of the year. Perhaps more significantly, faster and more powerful mobile devices hitting the market are producing and consuming content at unprecedented levels. Global mobile data grew 70 percent in 2012, according to a recent report from Cisco, which makes much of the gear that runs the Internet. Yet the capacity of the world's networking infrastructure is finite, leaving many to wonder when we will reach the upper limit and what we will do when that happens.

There are ways to boost capacity, of course, such as adding cables, packing those cables with more data-carrying optical fibers and off-loading traffic onto smaller satellite networks, but these steps simply delay the inevitable. The solution is to make the overall infrastructure smarter. Two main components are needed: computers and other devices that can preprocess and possibly filter or aggregate their content before tossing it onto the network, along with a network that better understands what to do with this content, rather than numbly perceiving it as an endless, undifferentiated stream of bits and bytes.

To find out how these major advances could be accomplished, SCIENTIFIC AMERI-



Photograph by David Yellen

CAN spoke with Markus Hofmann, head of Bell Labs Research in Holmdel, N.J., the research and development arm of Alcatel-Lucent that, in its various guises, is credited with developing the transistor, the laser, the charge-coupled device and a litany of other groundbreaking 20th-century technologies. Hofmann—who joined Bell Labs in 1998, after earning his Ph.D. at the University of Karlsruhe in Germany—and his team see "information networking" as the way forward, an approach that promises to extend the Internet's capacity by raising its IQ. Excerpts follow.

SCIENTIFIC AMERICAN: How do we know we are approaching the limits of our current telecommunications infrastructure?

HOFMANN: The signs are subtle, but they are there. A personal example: When I use Skype to send my parents in Germany live video of my kids playing hockey, the video sometimes freezes at the most exciting moments. In all, this doesn't happen too often, but it happens more frequently lately—a sign that networks are becoming stressed by the amount of data they're asked to carry.

We know that Mother Nature gives us certain limits—only so much information you can transmit over certain communications channels. That phenomenon is called the nonlinear Shannon limit [named after former Bell Telephone Laboratories mathematician Claude Shannon], and it tells us how far we can push with today's technologies. We are already very, very close to this limit, within a factor of two roughly. Put another way, when we double the amount of network traffic we have today—something that could happen within the next four or five years—we will exceed the Shannon limit. That tells us there's a fundamental roadblock here. There is no way we can stretch this limit, just as we cannot increase the speed of light. So we need to work with these limits and still find ways to continue the needed growth.

How do you keep the Internet from reaching "the limit"?

The most obvious way is to increase bandwidth by laying more fiber. Instead of having just one transatlantic fiber-optic cable, for example, you have two, or five, or 10. That's the brute-force approach, but it's very expensive—you need to dig up the ground and lay the fiber, you need multiple optical amplifiers, transmitters and receivers, and so on. To make this economically feasible, we need to not only integrate multiple channels into a single optical fiber but also collapse multiple transmitters and receivers using new technologies such as photonic integration. This approach is referred to as spatial division multiplexing.

> ***"What's needed is an infrastructure that no longer looks at raw data as only bits and bytes but rather as pieces of information relevant to a person using a computer or smartphone."***

Still, boosting the existing infrastructure alone won't be sufficient to meet growing communications needs. What's needed is an infrastructure that no longer looks at raw data as only bits and bytes but rather as pieces of information relevant to a person using a computer or smartphone. On a given day do you want to know the temperature, wind speed and air pressure, or do you simply want to know how you should dress? This is referred to as information networking.

What makes "information networking" different from today's Internet?

Many people refer to the Internet as a "dumb" network, although I don't like that term. What drove the Internet initially was non-real-time sharing of documents and data. The system's biggest requirement was resiliency—it had to be able to continue operating even if one or more nodes [computers, servers, and so on] stopped functioning. And the network was designed to see data simply as digital traffic, not to interpret the significance of those data.

Today we use the Internet in ways that require real-time performance, whether that is watching streaming video or making phone calls. At the same time, we're generating much more data. The network has to become more aware of the information it's carrying so it can better prioritize delivery and operate more efficiently. For example, if I'm doing a video conference in my office and turn my head away from the screen to chat with someone who has just entered my office, the conference setup should know to stop transmitting video until my attention returns to the screen. The system would recognize that I am no longer paying attention and not waste bandwidth while I'm speaking with the person in my office.

How do you make a network more aware of the information it's carrying?

There are different approaches. If you want to know more about the data crossing a network—for example, to send a user's request for a Web page to the closest Web server—then you use software to peek into the data packet, something called deep-packet inspection. Think of a physical letter you send through the normal postal service wrapped in an en-

velope with an address on it. The postal service doesn't care what the letter says; it's only interested in the address. This is how the Internet functions today with regard to data. With deep-packet inspection, software tells the network to open the data envelope and read at least part of what's inside. But you can get only a limited amount of information about the data this way, and it requires a lot of processing power. Plus, if the data inside the packet are encrypted, deep-packet inspection won't work.

A better option would be to tag data and give the network instructions for handling different types of data. There might be a policy that states that a video stream should get priority over an e-mail, although you don't have to reveal exactly what is in that video stream or e-mail. The network simply takes these data tags into account when making routing decisions.

Data traveling over the Internet already have identifying tags—why couldn't those be used?

It all depends on the level at which these tags are being used. For example, data packets that use Internet protocol have a header that includes the source and destination address. These could be considered "tags," but they provide very limited information. They don't indicate what Web site a user is requesting. They don't tell if the data belong to a [real-time] video stream or if they can be processed in batches. I'm talking about richer, higher-level tags or metadata that can in parts be mapped onto these lower-level tags.

Would prioritizing traffic based on information it contains cause the network to favor certain types of traffic at the expense of other types?

It should be no different from what we see already, for example, on our roads and streets. When we hear an emergency vehicle with sirens on, we are all expected to pull to the side, clearing the street to let the vehicle pass as smoothly and quickly as possible, maybe saving a person's life. The tag in this case is the siren—as long as we recognize there is an emergency, we don't need to know who is in the vehicle or what the problem is, and we behave accordingly. Should we also give certain Internet packets priority in case of an emergency? It's all about transparency and agreed-on behaviors—on the roads and also on the Net.

Even if a smarter Net can move data around more intelligently, content is growing exponentially. How do you reduce the amount of traffic a network needs to handle?

Our smartphones, computers and other gadgets generate a good deal of raw data that we then send to data centers for processing and storage. Sending all these data around the globe for processing in a centralized center will not scale in the future. Rather we might move to a model where decisions are made about data before they are placed on the network. For example, if you have a security camera at an airport, you would program it or a small computer server controlling multiple cameras to perform facial recognition locally, based on a database stored in a camera or server, before putting any information out on the network.

How does information networking address privacy concerns?

At the moment, privacy is binary—either you keep your privacy, or you have to give it up almost entirely to obtain certain personalized services, such as music recommendations or online coupons. There has to be something in between that puts users in control of their information.

The biggest problem is that it has to be simple for the user. Look at how complicated it is to manage your privacy on social networks. You end up having your photos in the photo stream of people you don't even know. There should be the digital equivalent of a knob that lets you trade off privacy with personalization. The more I reveal about myself, the more personalized the services I receive. But I can also dial it back—if I'm willing to provide less detailed information, I can still receive some personalized, albeit less targeted, offers.

Cyberattacks tend to take advantage of the Internet's openness, so security is largely left to the computers and other devices that connect to the Net. What impact would information networking have on Internet security?

The information-networking approach provides the overall infrastructure with more awareness about the network traffic, which might be helpful in identifying and mitigating certain types of cyberattacks. Other factors could complicate this as well. I would expect—and hope—that data traffic will increasingly be encrypted to help provide true security and privacy. Of course, once data are encrypted, it becomes difficult to extract any information from them. This is a research challenge that will require new encryption schemes that maintain secrecy while permitting certain mathematical operations on the encrypted information.

Imagine, for example, that the income of each household in an area is encrypted and stored on a server in the cloud, so no one—except the authorized owner—can read the actual numbers. It might be helpful if the numbers were encrypted in a way that would allow software running in the cloud to calculate the average household income in the area—without identifying any of the actual households, purely by operating on the encrypted numbers.

Another approach might be to develop clever ways of managing encryption keys so they can be shared without compromising security. If done right, none of this should put any more burden on the user. That's the key and the challenge. Just think of how many users are actually encrypting their e-mails today—almost none, because it's extra work. SA

Larry Greenemeier is an associate editor at Scientific American.

MORE TO EXPLORE

Read an article by Markus Hofmann about the related need for "application-aware" networks: http://tinyurl.com/cj25voa

SCIENTIFIC AMERICAN ONLINE

Learn more about Markus Hofmann's work at ScientificAmerican.com/jun2013/hofmann



Ginkgo: The Tree That Time Forgot

by Peter Crane.
Yale University Press, 2013 ($40)

Readers of this fascinating history will be glad to know there is at least one life-form that owes its survival, not its destruction, to humans. That would be the ginkgo tree, which has remained unchanged since the age of the dinosaurs and which might have died off were it not for human care and cultivation. The tree with the distinctive fan-shaped leaves and sometimes stinky seeds took on a symbolic meaning in many Eastern religions, its nuts became a delicacy, and it has grown into one of the most popular urban street trees because of its resilience. Botanist Crane reminds us that plants, like people, can hide surprising life stories.



FOSSIL LEAVES
of a 19-million-year-old ginkgo



Probably Approximately Correct: Nature's Algorithms for Learning and Prospering in a Complex World

by Leslie Valiant. Basic Books, 2013 ($27.99)

Valiant, a computer science professor at Harvard University, takes as his point of departure Alan Turing's 1936 paper that laid the groundwork for modern computers. Turing was the first to suggest that computation was subject to finite rules and therefore capable of being carried out by machines. Valiant argues that all living things have been capable of computation since the beginning of time, using "ecorithms" to predict the future and adapt to it. His book is an engaging meditation on complexity and on how living things often unwittingly use math to navigate it.



High Price: A Neuroscientist's Journey of Self-Discovery That Challenges Everything You Know about Drugs and Society

by Carl Hart. Harper, 2013 ($26.99)

Hart, an associate professor at Columbia University, uses a mix of personal narrative and scientific research to argue for the decriminalization of drugs. When crack cocaine spread through his predominantly poor, black Miami neighborhood in the 1980s, Hart blamed the drug for increases in crime and gun violence. But later research by Hart and others showed that crack was not particularly addictive, nor did it make users more impulsive or violent, leading him to a revelation: although drugs can exacerbate social problems, they are rarely the cause. Hart's account of rising from the projects to the ivory tower is as poignant as his call to change the way society thinks about race, drugs and poverty.

> ***"I've conducted nearly twenty studies in which I've given cocaine to participants without incident."***
> **—Carl Hart**



How We Do It: The Evolution and Future of Human Reproduction

by Robert Martin. Basic Books, 2013 ($27.99)

Human babies are born extremely plump, with about four times as much fat as other comparably sized mammals. Why? The extra layers may help fuel rapid brain growth in the first year of life, writes Martin, a curator of biological anthropology at the Field Museum in Chicago, in this exploration of sex, conception, birth, breast-feeding and parenting in the animal world. He suggests that examining our evolutionary past can lead to improved reproduction in our future. For example, the time each month when a woman is fertile varies. Historical records and the cycles of close primate relatives may help tease out the intricacies of ovulation and conception, including which factors may be linked to developmental defects.

—Marissa Fessenden

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COURTESY OF PETER CRANE; SPECIMEN COURTESY OF THE SWEDISH MUSEUM OF NATURAL HISTORY

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His book *The Believing Brain* is now out in paperback. Follow him on Twitter @michaelshermer





CSI, Science

Where neuroscience meets criminology

In his best-selling essay entitled "Guns," Stephen King contrasts a mass killer's school yearbook picture, "in which the guy pretty much looks like anybody," and the police mug shot of someone who looks "like your worst nightmare."

Do criminals look different from noncriminals? Are there patterns that science can discover to enable society to identify potential felons before they break the law or to rehabilitate them after? University of Pennsylvania criminologist and psychiatrist Adrian Raine attempts to answer these and related questions in his book *The Anatomy of Violence: The Biological Roots of Crime* (Pantheon, 2013). Raine details how evolutionary psychology and neuroscience are converging in this effort. For example, he contrasts two cases that show new ways to look at the origins of wrongdoing. First is the example of "Mr. Oft," a perfectly normal man turned into a pedophile by a massive tumor at the base of his orbitofrontal cortex; when it was resected, he returned to normalcy. Second, we learn of a murderer-rapist named Donta Page, whose childhood was so horrifically bad—he was impoverished, malnourished, fatherless, abused, raped and beaten on the head to the point of being hospitalized several times—that his brain scan "showed clear evidence of reduced functioning in the medial and orbital regions of the prefrontal cortex."

The significance of these examples is revealed when Raine reviews the brain scans he made of 41 murderers, in which he found significant impairment of their prefrontal cortex. Such damage "results in a loss of control over the evolutionarily more primitive parts of the brain, such as the limbic system, that generate raw emotions like anger and rage." Research on neurological patients in general, Raine adds, shows that "damage to the prefrontal cortex results in [increased] risk-taking, irresponsibility, and rule-breaking behavior," along with personality changes such as "impulsivity, loss of self-control, and an inability to modify and inhibit behavior appropriately" and cognitive impairment such as a "loss of intellectual flexibility and poorer problem-solving skills" that may later result in "school failure, unemployment, and economic deprivation, all factors that predispose someone to a criminal and violent way of life."

What is the difference between an aggressive tumor and a violent upbringing? One is clearly biological, whereas the other results from a complex web of biosocial factors. Yet, Raine points out, both can lead to troubling moral and legal questions: "If you agree that Mr. Oft was not responsible for his actions because of his orbitofrontal tumor, what judgment would you render on someone who committed the same act as Mr. Oft but, rather than having a clearly visible tumor, had a subtle prefrontal pathology with a neurodevelopmental origin that was hard to see visually from a PET scan?" A tumor is quickly treatable, but an upbringing—not so much.

We also need an evolutionary psychology of violence and aggression. "From rape to robbery and even to theft, evolution has made violence and antisocial behavior a profitable way of life for a small minority of the population," Raine writes. Theft can grant the perpetrator more resources necessary for survival and reproduction. A reputation for being aggressive can grant males higher status in the pecking order of social dominance. Revenge murders are an evolved strategy for dealing with cheaters and free riders. Even child murder has an evolutionary logic to it, as evidenced by the statistic that children are 100 times more likely to be murdered by their stepfather, who would have an interest in passing on his own genes over a rival's, than their natural father.

An evolutionary psychology and neuroscience of criminology is the next and necessary step toward producing a more moral world. In Raine's concluding remarks, he exhorts us to "rise above our feelings of retribution, reach out for rehabilitation, and engage in a more humane discourse on the causes of violence." Although some people may balk at the biological determinism inherent in such an approach and others may recoil from the preference for rehabilitation over retribution, we can all benefit from a scientific understanding of the true causes of crime. SA

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Illustration by Anthony Tremmaglia

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 33 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.



Rumen with a View

Mary Roach's new book, *Gulp*, explores our inner tubes

Groucho Marx said, "Outside of a dog, a book is a man's best friend. Inside of a dog it's too dark to read." With this wisdom available for decades, the question arises: Why did author Mary Roach stick her arm inside a living cow's stomach, where it's too dark to write? Answer: Because that's the kind of thing Roach does when she's researching books that will be read outside of a dog. Also, the bovine was what's called a fistulated cow, meaning that you can get in through a hidey-hole, which is important because it's exceedingly messy to go in any other way.

I met with Roach in early April when she visited New York City to promote her latest book, *Gulp: Adventures on the Alimentary Canal*. I last wrote about her in 2010 when her book *Packing for Mars* came out, which dealt in part with the unfortunate realities of hitting the head in a weightless environment. "People who hadn't read the book, who only heard the publicity, believe that I wrote an entire book about going to the bathroom in zero gravity," Roach told me. "It's not true—it was one chapter. But that chapter drew a tremendous amount of attention. Which also led me to think I'm not the only one with a 12-year-old's sensibility when it comes to these things."

Gulp begins with a description of a taste test and ends with a first-person account of a colonoscopy. It thus covers "the whole food chute," as Roach put it.

As do many great literary works, this book owes its existence to an editor who had a profound influence on a writer. "Many moons ago," Roach recalled, "the assignment was 'flatulence.' And I went to [the originators of] Beano, where they have a research center and I was a subject. And my editor at the time did not have quite the same sense of fun that I do—she let the air out of the story—so the piece, I felt, was not able to capture the true joys and surprises of flatulence research. And I got the sense that there was just so much more fun to be had on the alimentary canal."

Indeed, what could be more fun than wiggling your fingers, encased in a plastic sleeve though they may be, inside a cow's rumen (which, according to *Gulp,* is "the largest of its four stomach compartments" and "the size of a thirty-gallon trash can")?

Fistulated cows are ag-school staples, Roach writes. Using just a topical anesthetic, veterinarians cut a hole the size of a coffee can cover in the hide and a similar opening in the rumen. They stitch the two holes together, put a plastic stopper on the surface and, voilà, a "holey cow," as the ag students call it. (A fistula is an abnormal biological passageway, not a place to shove in your fist.) Roach's close encounter happened at the University of California, Davis, where the cows offer students instruction that is exceptionally vivid, if not quite disarming.

"Inside the rumen, it's fermenting," Roach told me. "It's a composter, it's hot in there. The cow is breaking down its food by bacterial action. We're using gastric acid and enzymes; the cow has a fermenter going on. Plus, you put your arm in there and you feel these amazing contractions. I actually was worried that a finger would break," she ruminated in multiple ways. "So it's a pretty instantaneous and unforgettable introduction to the digestion of animals other than us."

Of course, many humans have had instantaneous and unforgettable introductions to the digestion of animals, for example, tigers or crocodiles. Such passages usually lead to tails rather than tales. Fortunately, Roach survived both probing and being probed and emerged from deep contemplation of beast bellies, like Jonah, with a fascinating story to tell. With Roach at the tiller, *Gulp*'s canal cruise is tasty popular science writing: informative, entertaining and highly digestible. SA

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Illustration by Matt Collins

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Innovation and discovery as chronicled in *Scientific American*



June 1963

Intro to Exoplanets

"A planet-sized 'dark companion' has been discovered revolving around a dim star some six light-years distant in the direction of the constellation of Ophiuchus. The 'sun' of this solar system is Barnard's star, otherwise known chiefly for having the largest motion across the sky of any star. The planet is 50 percent more massive than Jupiter; it has been named Barnard's star B by its discoverer, Peter van de Kamp of Swarthmore College. Van de Kamp pointed out that although Barnard's star and its companion are the third known 'solar system' outside our own, they constitute the first such pair in which the companion is small enough to be classified confidently as a planet."

Post-Babel

"Machine translation of Chinese would seem to offer the only realistic hope of giving the West ready access to the manners, achievements and aspirations of a fourth of the human race. The Indo-Chinese group of nations, with a population of about 750 million, is currently publishing in newspapers, journals and books about three billion words a year. Less than 1 per cent of this vast output is now being translated and republished in English, French or German (undoubtedly a larger percentage is being translated into Russian). Automatic translation is needed because human translators cannot handle the volume or hope to acquire the special technical vocabulary needed."

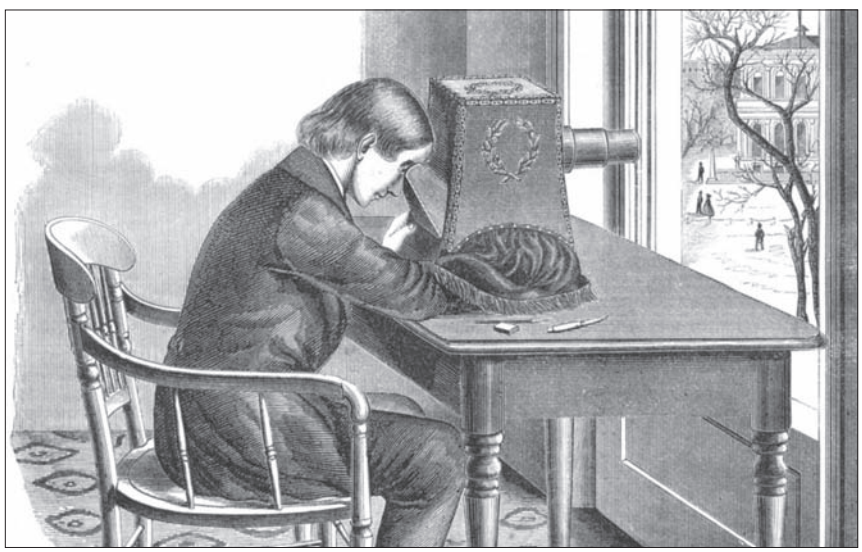


June 1913

Submarine Communication

"The Navy Department has adopted a 'submarine violin' for the transmission of messages between submarine torpedo boats and shore stations or other vessels. The mechanism is an adaptation of the violin. From one side of the submarine project two steel stays. From the ends of these is stretched taut a piano wire. Touching the wire is the roughened rim of a wheel which, when it revolves, sets up vibrations in the wire. An ordinary Morse key is used, and dots and dashes are hummed on the wire. The experiments at Hampton Roads, Va., showed that the vibrations may be heard clearly at a distance of five miles."

For a slide show on submarines and ships, see www.ScientificAmerican.com/jun2013/ships



CAMERA OBSCURA: The device projected a scene onto paper or canvas, where an artist could trace or copy it by hand, 1863

SCIENTIFIC AMERICAN, VOL. VIII, NO. 23, JUNE 6, 1863

Parachute Flaw

"That parachutes are not an absolute provision against accidents which may prove fatal, is shown by the harrowing experience of Arthur Lapham at the Aeronautical Society's flying carnival on Staten Island. With the Stevens pack [after A. Leo Stevens, a parachute pioneer] upon his back, Lapham was to drop a mile from a Wright biplane. At a height of a few hundred feet—three hundred, according to some spectators—Lapham slid from his seat and shot down. The parachute did not open, probably because the drop was too short. Fortunately for Lapham, he landed without injury on the marshy salt meadow flats near Prince's Bay. He was buried up to his armpits in mud and had to be dug out."


Scientific American.

June 1863

Camera before Film

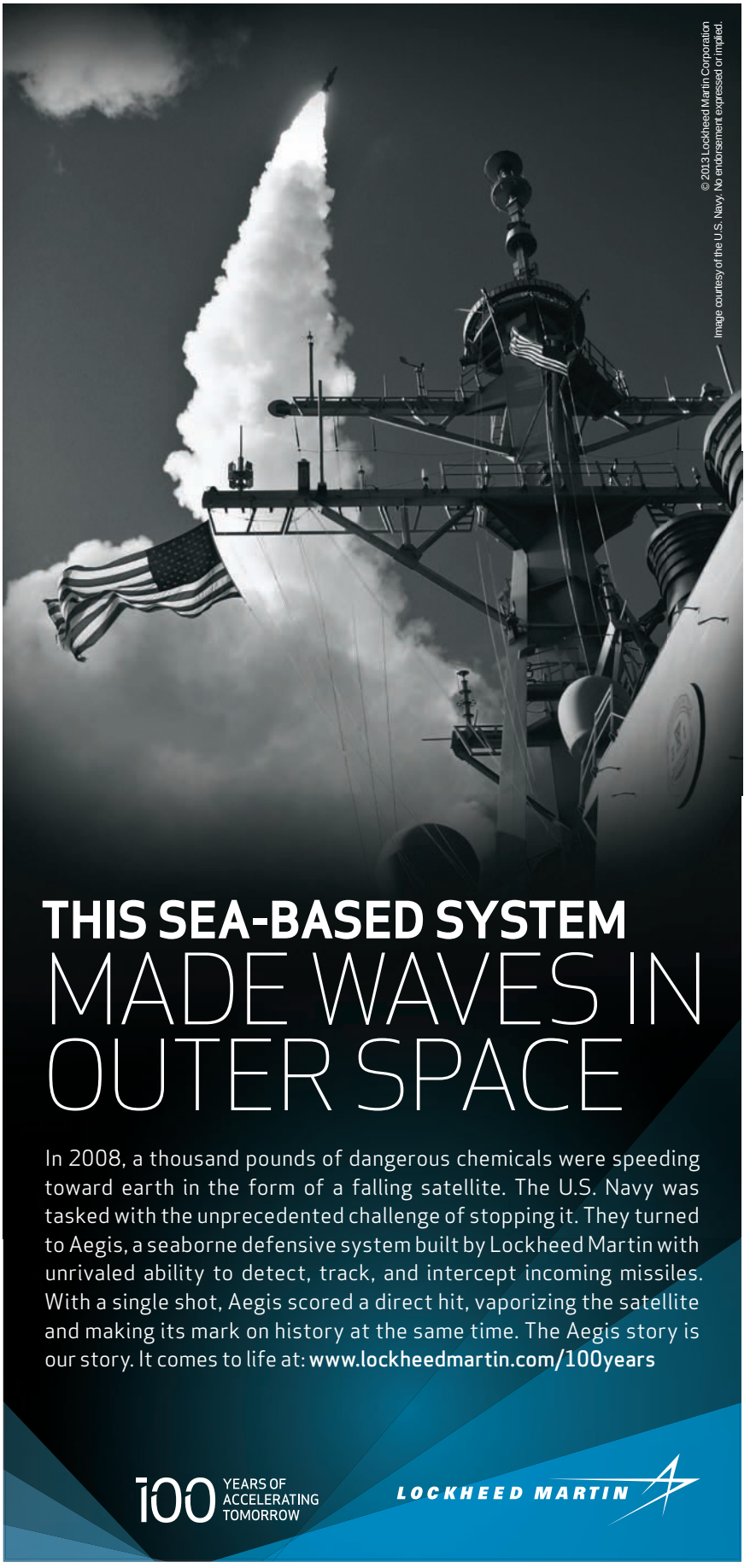
"A very valuable aid to artistic culture of the hand and eye is found in the 'camera obscura.' The object to be depicted is reflected through the lens onto the mirrors and then onto the white paper or canvas below [where it can be traced or drawn]. The artist's hand is introduced through the side opening covered by the curtain. The newly patented model combines desirable qualities with an elegant exterior. Our illustration shows a perspective view of the device and a student depicting the City Hall of New York."

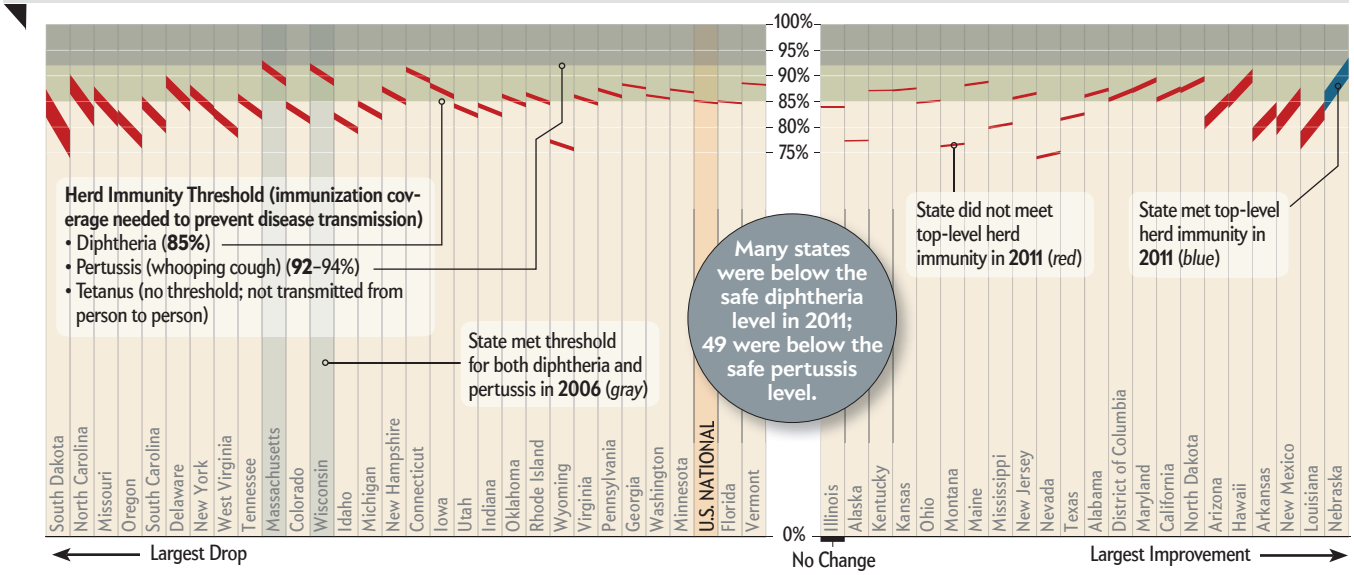
Horsepower

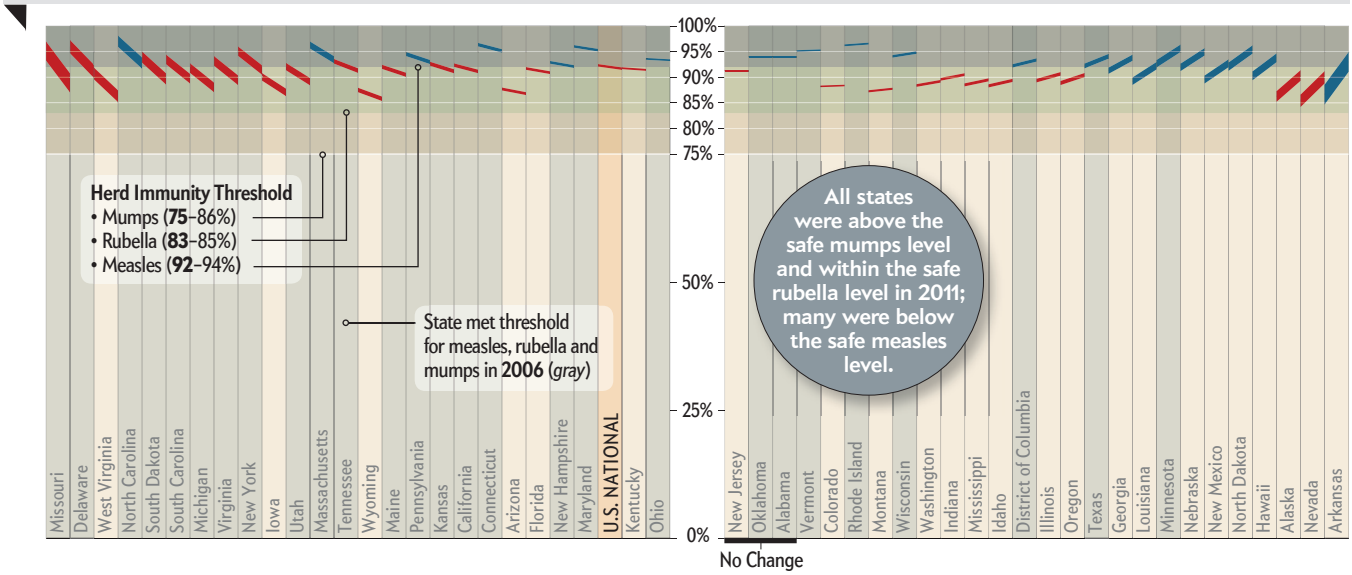
"The experiments with steam-powered navigation on the Erie Canal are said to have proved unsatisfactory. One firm has taken the engines out of its boats and is having the vessels converted into horse-towing boats."

Manpower

"Laborers are so scarce in Michigan that in some localities women have been obliged to labor in the fields. Wages are high."







The Danger of Opting Out

A rise in unvaccinated children poses a public health threat

Although vaccination rates for U.S. children are high overall, many states are dropping below safety thresholds. That is because parents are opting out of state vaccination requirements for kids entering public school, despite a dearth of evidence that vaccines are harmful or unnecessary. "The vast majority of their concerns have no basis in science," says William Schaffner, chair of preventive medicine at Vanderbilt University.

If enough parents in a community refuse or delay their children's vaccinations, an infectious disease can spread among many individuals. The outbreak can threaten all unvaccinated children, vaccinated children and adults who have weak immune systems, and babies who are too young to get their shots.

When vaccinations drop below the herd immunity threshold—the proportion of immune individuals needed to prevent widespread transmission—outbreaks rise. The 2012 U.S. outbreak of whooping cough (pertussis), which infected 42,000 people, was the largest since 1955. Rates for two crucial childhood vaccines, DTP (diphtheria, tetanus and pertussis) and MMR (measles, mumps and rubella), are falling (*above*). Other rates, such as for polio, are stable (*not shown*). —*Mark Fischetti*

SCIENTIFIC AMERICAN ONLINE
See more on adult vaccination rates at ScientificAmerican.com/jun2013/graphic-science

SOURCE: CENTERS FOR DISEASE CONTROL AND PREVENTION (*various survey methods*)

Graphic by Jan Willem Tulp